The University of Alberta

Quaternary Geology of the Western Cypress Hills Region, Alberta and Saskatchewan

by

© Norman Rhoderick Catto

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ABSTRACT

The Western Cypress Hills region was glaciated at least three times during the Quaternary. Throughout this time, the surface of the Cypress Hills Plateau remained unglaciated. The most extensive of the glacial events, Phase A, occurred some time prior to the Wisconsin. Phase B ice, of Illinoian or Early Wisconsin age, covered much of the region and was responsible during its retreat for the formation of Lake Wild Horse and several lakes in the Pakowki basin. Phase C ice, of Late Wisconsin age, achieved a maximum position marked by a pronounced moraine extending northeast from Etzikom, Alberta, to a position south of Medicine Hat and thence easterly to Irvine and Walsh, Alberta. This phase marked the maximum extent of Late Wisconsin ice into the region. Isostatic depression of the Pakowki basin at this time produced a second series of lakes. Retreat of the Phase C glacier was followed by a period characterized by a gradual climatic amelioration, which climaxed between 8500 and 7000 B.P. Climatic conditions then altered, and a cooler, moister period began, which continues to the present.

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QUATERNARY GEOLOGY OF THE WESTERN CYPRESS HILLS REGION, ALBERTA AND SASKATCHEWAN

INTRODUCTION

The Cypress Hills region of southeastern Alberta and southwestern Saskatchewan has long been an area of interest to scientists. The elevated plateau provided an environment and ecology totally different from that of the surrounding prairie. The hills served as a landmark and oasis for many early travellers since their discovery by LaVerendrye in 1743. Speculation considering their origin, geological setting, and significance to the native peoples has been rife.

During the early 1970's, interest in the region was focused on its archaeological importance by a series of studies undertaken under the auspices of the Alberta Archaeological Survey and the Alberta Department of Parks and Wildlife. The discovery of a multi-component site near Elkwater led to an inquiry into the position of the site with respect to both the local and regional geological setting. It was felt that an investigation of the Quaternary geology of the region and its relationship to archaeological events and development would be valuable. The Author was delegated the responsibility of conducting this investigation.

A) Objectives

The objectives of this research were:

1) To describe the physical properties, stratigraphic relationships, and palaeontological assemblages of the Quaternary deposits of the Western Cypress Hills region.

2) To construct a comprehensive glacial and post-glacial geological and palaeontological chronology.

3) To analyse the significance of these conclusions with respect to the archaeology of the Western Cypress Hills region.

B) Physical Setting

The Western Cypress Hills region encompasses the southeastern corner of Alberta and a small portion of southwestern Saskatchewan. The study area, illustrated in Figures 1 and 2 (in pocket), comprises approximately 10,200 km^2, of which 9,100 km^2 are located in Alberta. Physiographically, the region is dominated by the Cypress Hills, a southeastward-sloping flat-topped gravel-covered plateau which reaches a maximum elevation of 1,450 m near Elkwater, Alberta. This plateau is truncated abruptly by an escarpment along its northern flank, and stands 150 m above the gently northeastward-sloping plain. To the south, the plateau is bordered by a series of narrow, ill-defined, and dissected steppes.

To the north of the plateau, the physiography of the region is characterised by gently undulating plains with belts of

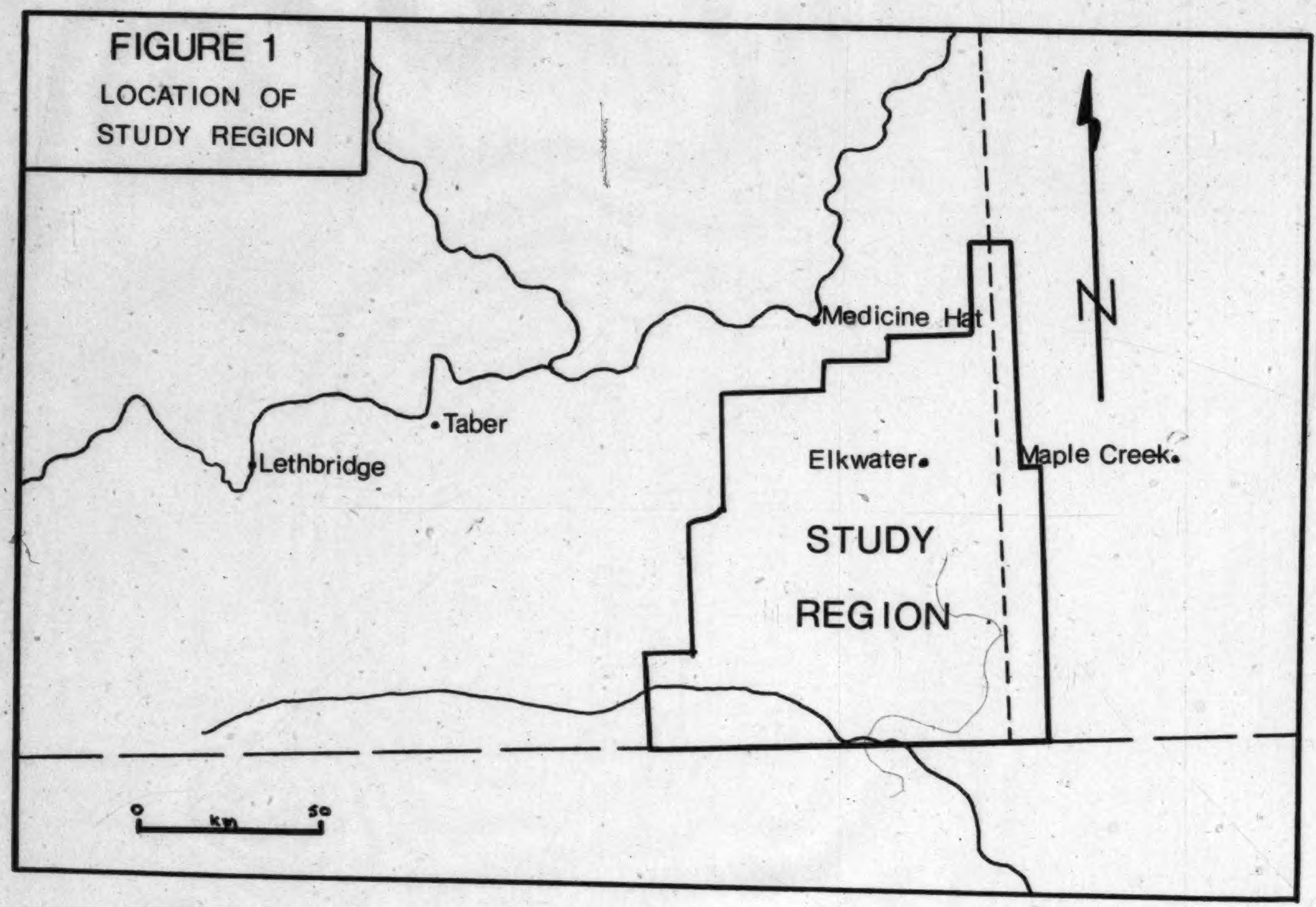


FIGURE 1
LOCATION OF
STUDY REGION

Medicine Hat
Taber
Lethbridge
Elkwater
Maple Creek
STUDY REGION
N
0
km
50

hummocky knob and kettle terrain and interspersed lake basins. Drainage in this area is effected by an integrated dendritic system discharging into the South Saskatchewan River through Ross Creek, and a second integrated dendritic system discharging into Many Islands Lake through Boxelder Creek. Most of the major streams in this area are permanent. An isolated area of well-dissected terrain (badlands) is present immediately to the south of the municipality of Irvine, Alberta.

The southern third of the study region is a steppe-like series of low plains, and contains extensive badland areas. Fluvial erosion of this zone has obviously been an effective modifier of the topography in the past. Currently, however, the only permanent stream in the area is the Milk River, which flows along the regional slope to the southeast. Several broad depressions which formerly contained lakes exist in the eastern portion of the area. Some of these have been dammed and converted to reservoirs for agricultrual purposes.

In the central western portion of the region, the shallow landlocked Pakowki Lake depression, currently occupied by a swamp, is fed by a number of intermittant streams. Chief among these is Etzikom Coulee Creek, which enters the basin from the west. The Pakowki drainage system is separated from the South Saskatchewan basin by a belt of hummocky moraine abutting Etzikom Coulee and Pakowki Lake along the north, and from the Milk River Basin by a complex of moraines, ice-thrusted bedrock, and bedrock ridges.

Thus, the Cypress Hills form a major drainage divide between the South Saskatchewan drainage basin to the north and the Milk River (Missouri) drainage to the southeast. The extents of the watersheds to the west of the Plateau have altered since preglacial time. The pattern of buried fluvial channels excavated in bedrock suggests that the drainage divide has migrated to the north as a result of Quaternary glaciation (Farvolden 1963).

C) Climate

The climate of the lowland areas surrounding the Cypress Hills may be classified as middle latitude steppe, characterised by cold, dry conditions during the winter and warm, dry summers. The mean annual temperature at Medicine Hat is 5.5°C, while at Manyberries the corresponding value is 4.1°C (Longley, 1972). The mean annual precipitation in the region is 350 mm, a value considerably less than the average annual potential evapotranspiration loss of 571 mm (Borneuf, 1976). On the Cypress Hills plateau, a cool boreal climate prevails, especially on north - and northwest - facing slopes. Annual precipitation exceeds 400 mm for the plateau as a whole (Longley, 1972) and the value for north-facing slopes is probably in excess of 450 mm, as suggested by the vegetation present. The mean annual temperature is approximately 2.5°C, and the range of temperature fluctuations is considerably less than on the surrounding plains. Although no data concerning evaportranspiration potential is available for the plateau area, the vegative community present suggests that the area enjoys the effects of a positive net moisture budget.

D) Vegetation

The study area may be divided into three vegetative zones: the northern prairie, southern prairie, and Cypress Hills Plateau area.

The northern prairie zone is dominated by short grass and rough fescue vegetation. The dominant species are Festuca scabrella, Stipa comata, Bouteloua gracilis, and Agropyron dasystachyum (Budd and Best, 1969). Arboreal species are confined to the major river valleys where examples of Populus tremuloides and Populus balsamifera are common. Acer negundo, locally abundant, was probably largely introduced into the region.

The southern prairie zone is characterised by relatively sparse vegetation, dominated by short-grass species. Artemisia spp., Shepherdia sp, Sarcobatus spp, Selaginella densa, Stipa comata, and Opuntia polyancantha are all quite common, while truly arid-region species such as Yucca glauca are found on some southern-aspect slopes (Budd and Best, 1969). Many north-facing slopes are characterized by a vegative assemblage similar to that of the northern prairie area.

Prior to the clearance for agricultural purposes, the pre-1900 vegetation of the Cypress Hills Plateau was a Boreal Forest (lower Foothills) assemblage (Rowe, 1972). The dominant species on well-drained slopes and on the upper plateau surface is *Pinus contorta*, with associated *Populus tremuloides*, *P. balsamifera*, *Picea glauca*, *Abies balsamifera*, and *Betula papyrifera*. In local depressions, *Picea mariana* and *Larix laricina* are common. The understory vegetation is dominated by *Lycopodium annotinum*, *Cornus canadensis*, *Ranunculus macounii*, *Pterospora andromeda*, and *Chimaphila umbellata*, all of which thrive in a boreal environment (Budd and Best, 1969). The transition from the northern prairie zone to the plateau is abrupt, but gradational changes characterise the other zonal boundaries.

The microphytic aqueous flora is dominated by species of diatoms. Genera preferring eutrophic waters form the vast majority of the population in the sloughs and reservoirs of the region, as well as in Pakowki, Murray, Seven Persons, and Many Island Lakes. Chief among those collected by the Author are Cyanophyta: *Microcystis*, *Anabaena*, and *Aphanizomenon*. *Charophyta* species are also found in eutrophic conditions. The only mesotropic lake in the region was Elkwater Lake: the dominant species here is *Melosira granulata*, while *Stephanodiscus spp*, *Fragilaria crotonensis*, *Ceratium sp*, and *Anabaena sp* are also present. The diatom assemblages of the Milk River and Irvine, Ross, and Mackay Creeks were dominated by *Navicula* and *Diatoma*, while Medicine Lodge, Sage, and Etzikom Creeks contained a low population of *Navicula* and *Microcystis*, in addition to *Charophyta*.

E) Fauna

Three vertebrate faunal zones corresponding to the vegative zones can be recognized in the study area. The southern zone is dominated by *Odocoileus hemionus* (mule deer). *Antilocapra americana* (prong horn), *Lepus townsendii* (white tailed jack rabbit), *Citellus richardsonii* (Richardson's ground squirrel), *Cynomys ludovicianus* (black tailed prairie dog), *Zapus princeps* (western jumping mouse), and *Microtus pennsylvanicus* (meadow vole), (Soper, 1964). The chief predators are *Crotalus viridis* (prairie rattlesnake), and *Canis latrans* (coyote). In the northern prairie zone, *Sorex sp* (shrew), *Lepus townsendii*, *Citellus richardsonii*, *Odocoileus virigianus* (white tailed deer) and *Antilocapra americana* are common, while *Canis latrans*, *Vulpes fulva* (fox), and *Mustela sp.* (weasel), are the dominant predators. *Crotalus viridus* is found on south-facing slopes. In the Cypress Hills Plateau, a boreal forest assemblage dominated by *Eutamias minimus* (least chipmunk), *Ondrata zibethicus* (muskrat), *Erethizon dorsatum* (American porcupine), *Vulpes spp.*, *Procyon lotor* (racoon), and *Lynx canadensis* (Canadian lynx), was present prior to the clearing of the area for agricultural purposes (Soper, 1964). All of the formerly indigenous large mammals, such as *Ursus arctos horribilis* (Prairie grizzly bear), *Canis lupus* (timber wolf), *Felis concolor* (cougar) *Cervus canadensis* (wapiti) and *Bison bison bison*, have become locally extinct in natural habitats. Of the wide variety of invertebrate fauna found within the study region, the only classes which proved to be of value in palaeonenvironmental interpretation were the gastropoda and pelecypoda. Russell (1951) conducted a study of the terrestrial gastropoda of the northern escarpment of the Cypress Hills, and observed an assemblage typical of *Pinus* forests dominated by *Vertigo modesta*, *Discus cronkhitei*, *Euconulus fulvers*, and *Oreohelix sp.*, with examples of *Retinella sp.*, *Zonitoides sp.*, *Succinea sp.*, and *Gastrocopta sp.*, also being present. Modern aquatic gastropoda observed by the author in Ross and Mackay Creeks and along the shores of Elkwater Lake include *Helisoma trivolvis*, *H. antrosa*, *Gyraulus parvus*, and *Promenetus exacuous*. All of these species prefer quiet, shallow streams, ponds, or lakes with low turbidity and a mud or ooze substrate (Leonard, 1959). Pelecypoda noted in these water bodies were *Sphaerium patella*, *S. rhomboideum*, *Pisidium casertanum*, *P. ferrugineum*, and *Anodonta grandis*. These species also exhibit a preference for quiet, shallow streams, lakes and ponds with a mud substrate (Herrington, 1962; Clarke, 1973). The molluscan fauna of the Milk River was dominated by *Helisoma sp.*, *Pisidium ferrugineum*, *P. nitidum*, and *Anodonta grandis*. The most common gastropods in Pakowki, Many Island, and Murray Lakes were *Vertigo modesta* and *Gastrocopta sp.*, while pelecypod fauna was dominated by *Sphaerium patella*, *S. rhomboideum*, *S. occidentale*, *Pisidium casertanum*, *P. ferrugineum*, and *P. insigne*. Similar assemblages were noted in Medicine Lodge, Sage, and Etzikom Creeks. These assemblages suggest slow-moving currents, shallow depths, and intermittant periods of subaerial exposure (Herrington, 1962; Clarke, 1973).

F) Soils

The soils of the area north of the Cypress Hills Plateau are predominantly members of the Brown Chernozemic Great Group. These soils are characterised by the development of a humic-rich Ah horizon greater than 10 cm in thickness displaying granular structure and having an organic carbon content between 1% and 17% and a Munsell moist colour value in excess of 3.5 (CSSC, 1978). Inherent in the definition of the great group are the climatic conditions under which the soils form; a cool, subarid environment is required. The Ah horizon forms due to the leaching and humification of the calcareous parent material by short-grass vegetation (Clayton *et al*, 1977). In areas locally enriched in sodium, soils of the Solonetzic order are present, while floodplain districts and sloughs are characterised by Cumulic Regosols and Organic soils.

To the south of the Plateau, the presence of alkali salts in the groundwater flow system has resulted in the development of Solonetzic soils over large area. These soils are characterised by the presence of a hard columnar B horizon, with a Ca:Na ratio no greater than 10 (CSSC, 1978). Solodization, in some cases aided by improper irrigation practices, is proceeding in the area. Soils representing all phases of the solodization process, from saline Humic Regosols to Solonetzic Brown Chernozems, were observed by previous investigators (Wyatt et al, 1941), as well as by the author. Associated with the Solonetzic soils are minor areas of Gleysols in groundwater discharge areas and Brown Chernozems in elevated locations.

Brunisols, Luvisols, and Dark Brown and Black Chernozems are all found on the Cypress Hills Plateau. The thin Ah horizons and calcareous nature of the Burnisolic soils cause them to be classified within the Eutric Great Group. Commonly, they are found developed on landslide scars and debris of recent origin. The development of the Luvisolic and Chernozemic soils is controlled by vegetative cover (Pettapiece 1969), which in turn is controlled by elevation and aspect. Black Chernozems develop at higher elevations under grass cover, while at the base of the escarpment the Dark Brown Great Group dominates the open areas. Dark Grey and Orthic Grey Luvisols are found under forest cover on slopes with northerly aspects, the former in areas which have reverted to the vegetation present prior to clearing for agricultural purposes. Much of the plateau has been utilised as pastureland, and the Luvisolic soils are apparently slowly altering to Black Chernozems due to the change in vegetative cover despite the suitability of the climatic regime for forest encroachment.

PREVIOUS WORK

A) Archaeology

Approximately 100 sites have been investigated by archaeologists in southeastern Alberta and southwestern Saskatchewan. Of these, the most stratigraphically complete and complex is the Stampede Site, DjOn-26 (formerly DjOn-117), investigated by Gryba (1972, 1975). This locality, at the northern foot of the Cypress Hills escarpment 500 m east of Elkwater Lake (NE-19-8-2-W4), forms the focal point of the present study.

Excavation during the 1972 field season revealed a multi-component sequence with fourteen distinct culture horizons (Gryba, 1975), representing non-depositional intervals in the geological record. The age of the two lowest horizons, designated 12B and 12C, is unknown. However, a charred bone fragment found within culture hoirzon 12A, 3.5 m below the present ground surface, has yielded a radiocarbon date of 7245 ± 255 BP (NMC-571). The horizon probably represents the Bitterroot culture complex, on the basis of this date and the nature of the artifacts found within the unit (Gryba, 1975). Horizons 10 and 11 are also associated with this culture.

Culture horizons 10 and 11 are separated by a fluvial silt stratum 1.5 m thick that is devoid of artifacts. Interbedded in the silt is a 5 cm layer of volcanic ash, which has been identified as

Mazama tephra by Westgate (University of Toronto, personal communication, 1980). This tephra was ejected from Mount Mazama, Oregon, c. 6600 BP (Fryxell, 1965) and therefore serves as an isochron across the western Great Plains.

The Oxbow complex has been identified in two horizons, 7 and 8. These horizons are separated from the Bitterroot units by thin bands of fluvial silt and sand, and a cultural horizon of uncertain affinity (layer 9). The Oxbow horizons are overlain by two cultural units characterised by a paucity of material. Culture horizon 2, associated with the Besant complex, is separated from the underlying strata by a series of horizons marking a gradual transition from Oxbow to Besant culture (Gryba, 1975). In another pit located 40 m north of the main excavation site, artifacts associated with the marginally older Pelican Lake cultural complex have been discovered. Artifacts of Late Prehistoric to Early Historic age are exposed in culture horizon 1 of the DjOn-26 site (Gryba, 1972), as well as at a number of other sites in the Elkwater area (Elliot, 1971; Bonnichsen and Baldwin, 1973).

Although a minimum date for the initial occupation of the DjOn-26 site has been established at 7245±255 BP, no maximum date has as of yet been determined. The discovery of a juvenile human skull in mid-Wisconsin sediments near Taber (Stalker, 1969b), suggests that Southern Alberta was occupied c. 40000 BP. However, no additional human remains or artifacts have been recovered from the Taber section. In the absence of additional cultural material relevant to the initial occupation date of DjOn-26, the date of the earliest possible occupation must be influenced chiefly through the study of palaeoclimatic data and glacial ice front positions.

B) Quaternary Geology

The Quaternary geology of the western Cypress Hills region was first investigated by Dawson (1875, 1885) and McConnell (1885). These researchers identified the major physiographic features of the region, and recognized the presence of glacigenic sediments on the lowland and their absence on the Cypress Hills Plateau. McConnell (1885) delineated the upper limit of glacial erratics on the north slope of the Cypress Hills at 4400' (1400m), and was responsible for the discovery of almost all of the major river sections which subsequently formed much of the basis for the interpretation of the Quaternary geology of the region. The deposits were explained by Dawson and McConnell as ice-rafted material in accordance with the accepted theory of that era. However, both investigators recognized the inability of the drift ice theory to explain the numerous coulees paralleling the moraines, and conceded that meltwater from the ablation of the continental glaciers envisaged by Warren Upham could carve channels resembling the coulees.

Alden (1924, 1932) conducted extensive research in Montana, North Dakota, and the Cypress Hills region. In addition to recognizing the presence of glacially-produced material, he delineated four major periods of fluvial activity as indicated by gravel-floored benches. The earliest of these events, termed the "Cypress Plain", was recognized only on the Cypress Hills Plateau. The shingle deposit was assigned an Oligocene age on a palaeontological basis, and was known as the Cypress Hills Formation. Bench #1, referred to as the Flaxville bench, was assigned a Pliocene age and is the most extensively - exposed of the fluvial stages. Benches #2 and #3 were tentatively assigned to the Pleistocene, are not of great areal extent, and were not recognized in Canada. Alden observed the benches only in non-glaciated regions or on the protected southern slopes of nunataks (such as the Cypress Hills), and concluded that they were destroyed in Alberta and the more northerly areas of Montana and North Dakota by glaciation.

Johnston and Wickenden (1931, 1931 unpublished data) followed these preliminary efforts with a somewhat more detailed study of Quaternary sections found along the Oldman and South Saskatchewan Rivers to the north and west of the study area, as well as carrying out a general regional reconnaissance. They recognized the absence of Cordilleran elements in the till in southeastern Alberta, and differentiated this Canadian-Shield origin advance from the earlier glacial advance of Cordilleran affinity found to the west. A second, younger "Laurentide" advance was also recognized by Johnston and Wickenden, who stated

(p. 30):

> "The earlier ('Laurentide') ice-sheet appears to have advanced farther southwest and west than the later one...A moraine that extends south from Calgary to Okotoks probably marks the limit of the advance of the later ice sheet."

This moraine was correlated with another which abutted the north bank of Etzikom Coulee (Johnston and Wickenden, unpublished map).

The age of these two Canadian-Shield origin drift sheets was concluded to be Wisconsin. An older (Kansan) age was considered for the more extensive event, sediments of which were exposed in southeastern Alberta and northern Montana, but this hypothesis was tentatively discarded because "no definite boundary between the two drift sheets is known" (p. 37). The oldest till recognized by these authors along the Oldman River was assigned a Kansan age, but this unit was thought to be completely covered to the southeast. Johnston and Wickenden did, however, recognize the possibility that more detailed investigations could enable the two drift sheets to be adequately differentiated, both lithologically and chronologically. Alden (1932) also mapped end moraines in the region, his conclusions regarding correlation and chronology largely concurring with those of Johnston and Wickenden.

Warren (1937) delineated a major terminal moraine feature, the Viking moraine, which he indicated trended almost due south from Viking, Alberta, to the northern flank of the Cypress Hills. Subsequent investigators have failed to detect any evidence for an ice front position along the postulated trend of this feature.

Bretz (1943) mapped end and recessional moraines in eastern Alberta and southwestern Saskatchewan that were produced by glaciers originating from the Canadian Shield. The westernmost of these moraines was the Calgary-Okotoks feature previously noted by Johnston and Wickenden (1931). Bretz mapped a series of terminal moraine deposits extending east from Lethbridge between Chin and Etzikom coulees, continuing north of Pakowki Lake, and abutting the northern flank of the Cypress Hills in Alberta. These moraines, as well as a more southerly feature in Montana between the Milk and Missouri Rivers, the Calgary-Okotoks feature, and several discontinuous moraines to the north and west of Medicine Hat, were assigned an "Early" Wisconsin age (equivalent in current terminology to the earlier portion of the Late Wisconsin). The maximum extent of the "Late" Wisconsin or Altamont advance was marked by a moraine extending southeast from Two Hills, Alberta, through Kerrobert, Aquadell, and Gravelbourg, Saskatchewan. (see Figure 3).

Bretz suggested that each east-west trending coulee marked a terminal or standstill phase in the glacial history of southern Alberta. He envisaged a prolonged recession, punctuated by relatively minor standstill intervals, from the southernmost moraine west of Shelby, Montana, and north of Great Falls to the Altamont or Late Wisconsin moraine.

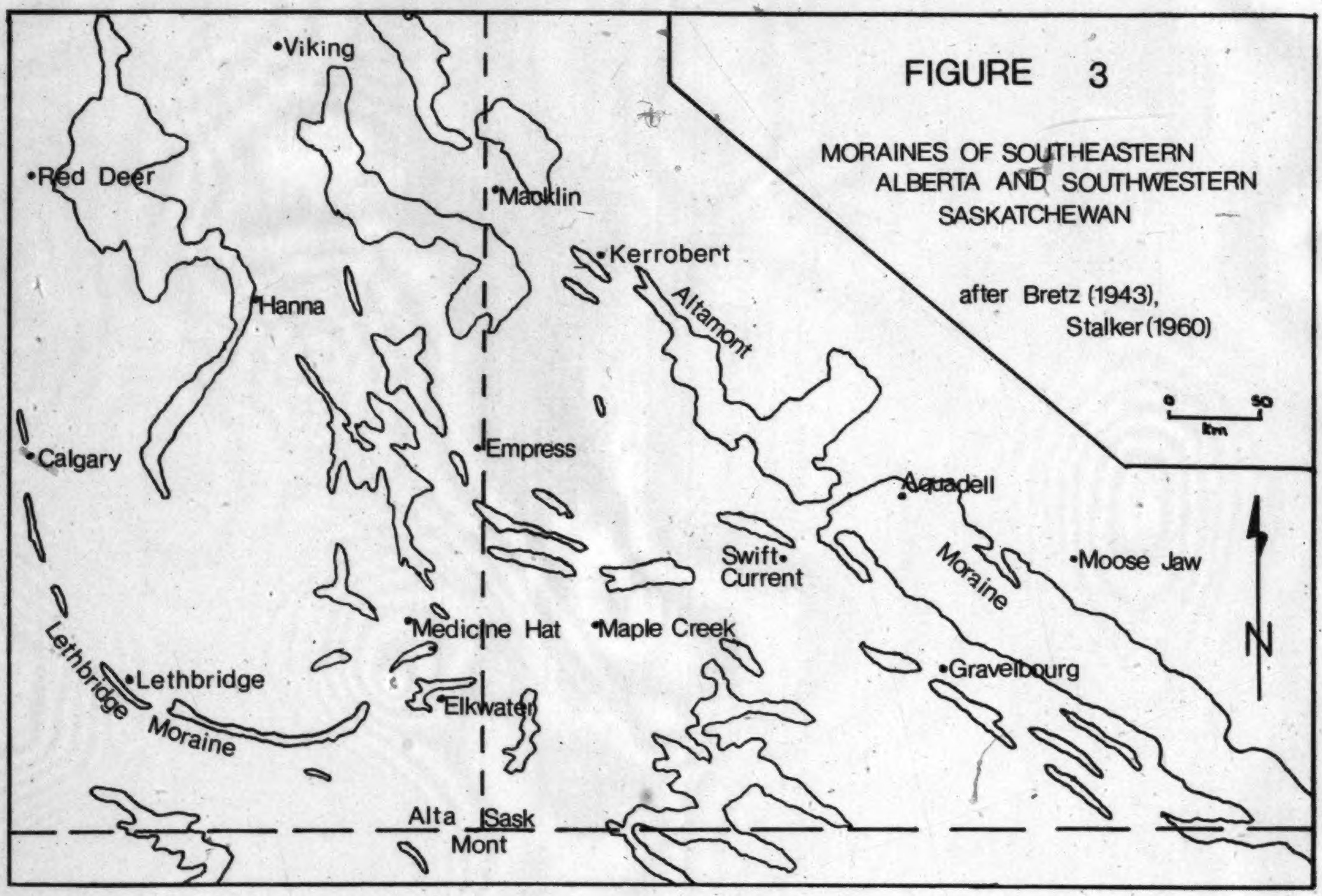


FIGURE 3

MORAINES OF SOUTHEASTERN ALBERTA AND SOUTHWESTERN SASKATCHEWAN

after Bretz (1943), Stalker (1960)

Red Deer
Viking
Hanna
Macklin
Kerrobert
Altamont
Calgary
Empress
Aquadell
Swift Current
Moose Jaw
Moraine
Medicine Hat
Maple Creek
Gravelbourg
Lethbridge
Lethbridge Moraine
Elkwater
Alta
Sask
Mont
0
50
km
N

Horberg (1952, 1954) applied the term "Lethbridge moraine" to the Calgary-Okotoks-Lethbridge-Etzikom coulee landform. He considered this feature to represent a major recessional or terminal moraine, and assigned it a Late Wisconsin age.

Stalker, in a series of papers published between 1956 and 1977, recognized a large number of Early and Mid-Quaternary advances and retreats affecting southern Alberta. These events are recorded in complex sections along the Oldman River (Stalker, 1963b, 1969b), in the Medicine Hat area (Stalker, 1969a, 1972), on the Blood Reserve southwest of Lethbridge (Stalker, 1963a), and in the Waterton area (Stalker and Harrison, 1977). Due to the complexity of the sections, no integrated sequence of glacial and interglacial events has yet been developed based on lithostratigraphy. However, biostratigraphic correlation between several of the major sections has proven feasible. The palaeontological data suggests that all of the major glacial and interglacial periods from the Kansan to the Wisconsin are represented (Stalker, 1969a, 1972). Investigation of deposits in the Wellsch Valley, Saskatchewan, area indicates on palaeontological grounds, that the oldest sediments of glacial affinity exposed there are of Late Nebraskan age (Stalker and Churcher, 1972).

Stalker (1977a), states that the youngest Canadian Shield originating advance to affect the western Cypress Hills region occurred during the Late Wisconsin, and reached its maximum at the point marked by the Lethbridge moraine. He thus considers all glacigenic material of Canadian Shield origin south and west of this moraine to be older than the Late Wisconsin; this conclusion also applies to the Erratics Train material in the Calgary area previously suggested to be Late Wisconsin (Stalker, 1956). No attempt has been made by Stalker to correlate the tills exposed south of the South Saskatchewan River in the western Cypress Hills region to any of the units present in the South Saskatchewan, Oldman, and Blood River sections.

The position of the maximum Late Wisconsin advance to the north of the Cypress Hills is considered uncertain by Stalker (1977a). He cites three possible ice-front positions, and has subsequently expressed a preference for the most northerly of these (Stalker, Geological Survey of Canada, personal communication, 1979). Figure 4 illustrates the position of the Lethbridge moraine in the study region, and the three postulated ice-front positions in the area north of the Cypress Hills.

The western Cypress Hills region was first intensely investigated by Westgate (1964, 1965b, 1968, 1972). He recognized five surficial till sheets, the oldest of which he tentatively assigned an Early Wisconsin age and termed the Elkwater glaciation (1965a). This event was preceded by a lacustrine event which deposited silt and clay beds (Wolf Island sediments) and a glacial advance (pre-Elkwater glaciation). The Elkwater glaciation marked the time of

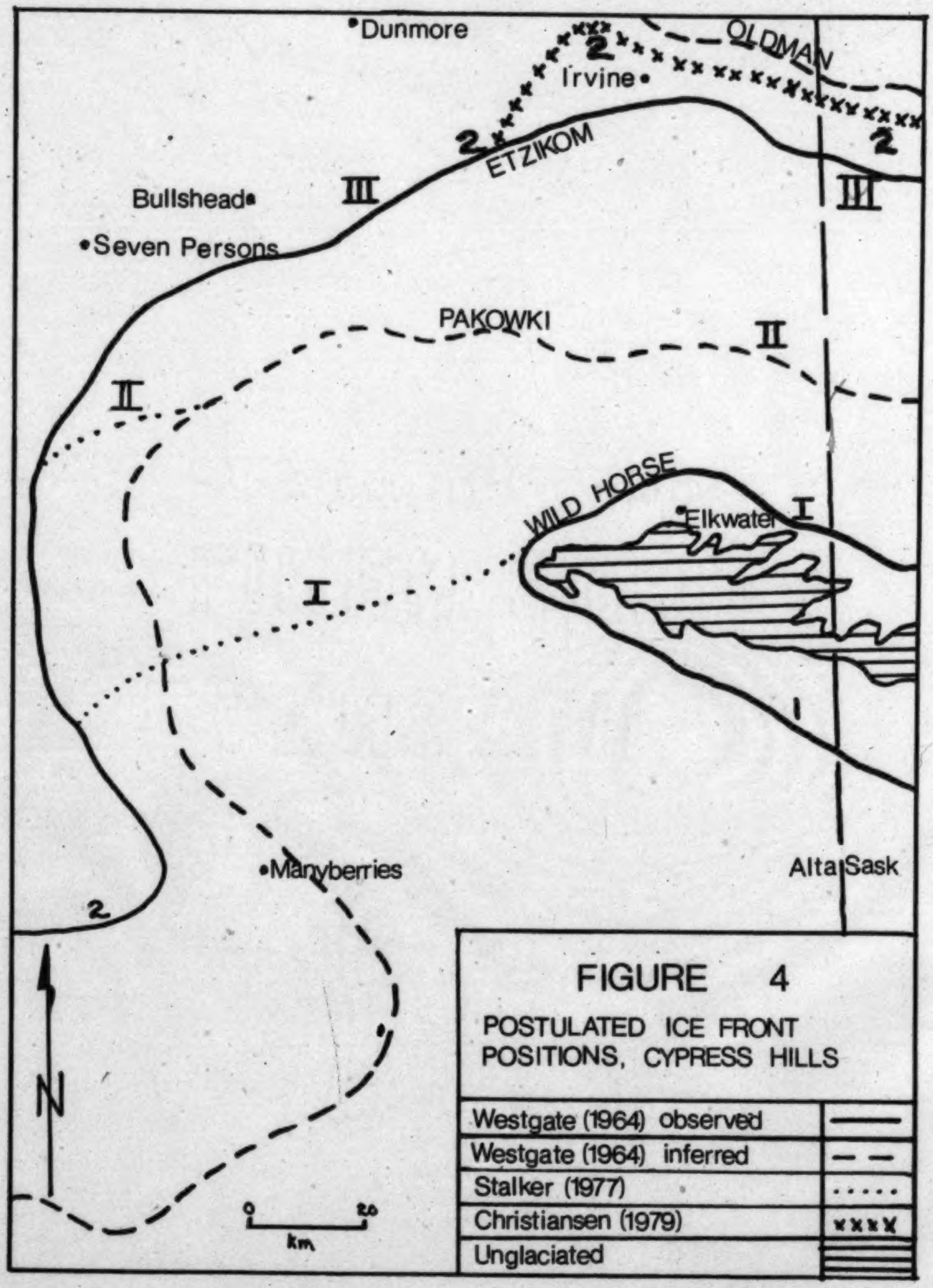

Dunmore
OLDMAN
2
Irvine
2
2
ETZIKOM
III
III
Bullshead
Seven Persons
PAKOWKI
II
II
WILD HORSE
Elkwater
I
I
1
Manyberries
Alta
Sask
2
N
0
20
km
Westgate (1964) observed
Westgate (1964) inferred
Stalker (1977)
Christiansen (1979)
Unglaciated

FIGURE 4

POSTULATED ICE FRONT POSITIONS, CYPRESS HILLS extensive ice coverage of the region, and was responsible for the deposition of erratics on the northern flank of the Cypress Hills to an elevation of 1375 m. On the southern slope, the Elkwater drift reaches an elevation of 1250 m. The remaining four glacial events - the Wild Horse, Pakowki, Etzikom, and Oldman glaciations - were assigned a Late Wisconsin age (Westgate, 1964, 1968). This chronology was primarily based on two points: the age assigned to deposits in Montana (Flint _et al_, 1959; Colton _et al_, 1961), and in North Dakota (Lemke, 1960) that were assumed to be correlative to the Alberta deposits by Westgate; and the presence of volcanic ash within lacustrine sediment overlying Pakowki till at Manyberries, Alberta, that was identified as Glacier Peak tephra. Westgate (1964) assumed an age of 14,000 to 15,000 BP for the underlying Pakowki till, placing the upper three drift sheets within the Late Wisconsin. This estimate was supported by subsequent radio-carbon dates of 12,000±310 BP (Fryxell, 1965) and 12,750±350 BP (Mudge, 1967, Ives _et al_, 1967) on mollusca associated with Glacier Peak tephra in Montana. The age of the Wild Horse till was based solely upon the postulated age of correlated tills in Montana and North Dakota.

The margins of the Wild Horse, Pakowki, and Etzikom drift sheets north of the Cypress Hills correspond to Stalker's (1977) ice front positions 1, 2, and 3 respectively. The frontal positions of each advance were recognized in part by the presence of terminal moraines. The maximum extent of the Wild Horse advance was determined by the moraines immediately abutting the Cypress Hills on the north and south, and the northernmost moraines in Montana previously mapped by Alden (1932) and Bretz (1943). In the Lake Pakowki area, the frontal position of the Pakowki advance was determined by the Pakowki moraine, a series of arcuate ridges enclosing the Pakowki basin along its southeastern margin. The position of this advance's maximum extent to the north of the Cypress Hills was interpolated between the Wild Horse and Etzikom moraines on the bases of clast mineralogy and pebble petrography. The Etzikom moraine west of Lake Pakowki was determined by Westgate (1964) to be correlative to the Lethbridge moraine of Horberg (1952) as was recognized originally by Johnston and Wickenden (1931 unpublished map). The northernmost ice frontal position, that of the Oldman glaciation, forms a broad arc between Walsh and the Oldman River north of Bow Island. The Wild Horse, Pakowki, and Oldman drift sheets were respectively renamed the Green Lake, Robinson, and Walsh in Westgate's 1972 paper.

Westgate also identified three major postglacial lakes: Lake Wild Horse, correlated with the retreat from the Wild Horse maximum position; Lake Pakowki, formed c. 12000 BP adjacent to the Etzikom moraine; and Lake Walsh, ponded against the Oldman ice front. Lacustrine sediments identified in the Medicine Hat area were believed to have formed in an embayment connected to Lake Walsh.

In addition to conducting an extensive study of the regional geomorphology, Westgate (1964, 1968) studied the lithology of the till units in some detail. He recognized a number of differences in clast mineralogy and pebble composition, both between and within the till units. Some of these differences were postulated to be due to the multiple directions of advance and source areas of the glacial events, while others were attributed to the variations in local bedrock lithology. Westgate (1972) suggested that the tills in a limited area could be distinguished on the basis of stone lithology and clast mineralogy, and used these criteria to differentiate till units where moraines were absent.

Recently, Westgate has stated that the Etzikom moraine represents the maximum extent of the Late Wisconsin ice sheet (Westgate and Evans, 1978, p.1565), thus placing him in agreement with Stalker (1977). Unfortunately, no reasons are presented for this conclusion, which modifies previous statements and leads to inconsistancies with his 1964, 1968 and 1972 descriptions of field sections and stratigraphic relationships. Changes in these descriptions have not yet been published, and the original references are cited uncorrected by Westgate and Evans (1978).

The Cypress Hills area of southwestern Saskatchewan has been investigated by Christiansen (1959, 1965, 1979). A large number of glacial and non-glacial sedimentary units were recognized.

In the Saskatoon area, units correlated to those in southwestern Saskatchewan have been separated into three groups (Christiansen, 1968): the Empress Group, a complex series of stratified sediments; the Sutherland Group, a series of tills and ice front proximal deposits; and the Saskatoon Group, composed of two tills (Floral and Battleford Formations) and interbedded stratified sediments. The Sutherland and Empress Groups are considered to be pre-Sangamon in age, while the Floral Formation is thought by Christiansen to be of Early Wisconsin age due to its stratigraphic position immediately overlying the fossiliferous Echo Lake Gravel (Christiansen, 1972). However, the age of the Floral Formation is now uncertain because the Wascana Creek ash which overlies the till in two localities northwest of Regina (Christiansen, 1961), has been fission-track dated at 0.68 million years (Westgate et al, 1977). At present, this conundrum is still unresolved.

The Battleford Formation, a unit of Late Wisconsin age, forms the surface deposits over the entire extent of Southern Saskatchewan with the exceptions of the Wood Mountain Upland and the Cypress Hills (Christiansen, 1979). Three major Late Wisconsin ice front positions have been recognized. An initial phase 1, corresponding to the Wild Horse glaciation of Westgate (1964), along the prominent end moraine southwest of Shaunavon, Saskatchewan, is considered to represent the Late Wisconsin maximal position. No direct evidence for the age of this phase was presented. Although Christiansen

(1979) was aware of the possibility of a pre-Late Wisconsin age for this event, he prefers an early Late Wisconsin (Woodfordian) age (Christiansen, Saskatchewan Research Council, personal communication, 1979), based on his stratigraphic correlation of the till exposed in the Shaunavon area to the Battleford Formation. An intermediate phase 2, with the ice front abutting the Pelletier Channel southeast of Swift Current, corresponds to the Etzikom position of Westgate (1964) and the Lethbridge moraine of Horberg (1952) and Stalker (1977). Phase 3, a recessional event represented by the Fox Valley moraine, represents a position north of Westgate's (1964) Oldman moraine, and is dated at approximately 15,500 BP by indirect evidence (Christiansen, 1979). Associated with this event is the formation of an ice-ponded feature, glacial Lake Bigstick, the western extension of which is correlative to Lake Walsh of Westgate (1964).

The most recent study of the Cypress Hills area of Alberta was undertaken by Barendregt (1977). He attempted to differentiate tills on the bases of mineralogy and magnetic fabric, and succeeded in recognizing three distinct units in the Pakowki Lake basin. Two of these tills were correlated to the Wild Horse and Pakowki units of Westgate (1964), and were assigned a pre-Late Wisconsin age, a conclusion reached chiefly through a study of the area's geomorphological development. The till north of the Etzikom moraine was correlated to the uppermost till recognized by Stalker (1977), and was assigned a Late Wisconsin age. Barendregt and Ongley (1979) are currently conducting a long-term study of slope recession in the Onefour area, in order to evaluate the influence of climatic factors.

In summary, it can be seen that the most contentious issue in the delineation of the Quaternary chronology of the western Cypress Hills region is the age of the tills located south of the Etzikom-Lethbridge moraine. No radiocarbon dates relative to the age of these sediments have yet been obtained from the region. Research conducted into the chronology of the volcanic tephra of Montana, Idaho and Washington (Mudge, 1967; Lemke _et al_ 1975; Porter, 1978) suggests that the tills are of Late Wisconsin age, based upon the stratigraphic relationship of the Manyberries ash and the Pakowki till as outlined by Westgate (1964). However, research in the Kananaskis (Jackson, 1977) tends to support the contention of Stalker (1977a) that the sediments are older than the Late Wisconsin. The depth and scope of the investigations of Stalker in southern Alberta give added credibility to his conclusions. The investigation of this chronological problem is of importance in regard to both the geological and archaeological succession of events in the region, and thus forms one of the most important aspects of the present study.

METHODS OF INVESTIGATION

A) Field

Field investigations entailed the systematic observation, description and sampling of more than 400 locations within the study region. A list of sample locations is presented as Appendix G. Aerial photographs and topographic maps were utilized in order to aid in the selection of sample locations and the recognition of large-scale geomorphic features. Although all types of Quaternary sediment and exposed bedrock present in the region were sampled, the greatest emphasis was placed on the investigation of the lacustrine, fluvial and aeolian deposits, since these sediments were potentially the most useful for chronological and paleoenvironmental determinations. In addition, a careful search was conducted for volcanic ash layers and buried or relict soil horizons.

Several sampling strategies were employed. Bulk samples for textural and mineralogical analysis were obtained from all exposures of lacustrine, fluvial and aeolian sediments. Samples for palaeontological analysis were obtained from the subaqueously-deposited silt and clay units. Oriented samples of lacustrine sands and silts and loess were taken, etched with hydrofluoric acid, and subsequently stained with sodium cobaltnitrate applied as a fine spray; the alignment of the discoloured potassium feldspars was ascertained and used to determine current and wind directions, respectively. Selected exposures of glacigenic sediments were investigated in order to facilitate the identification and correlation of units previously named by other researchers. Elevations were determined from topographic maps and surveying from bench marks.

The principal streams and lakes of the region were sampled for diatoms, ostracods and molluscs, the organisms being trapped upon the filtration of water samples through a series of sieves ranging in mesh size from 0.84 mm (#20) to 0.044 mm (#325). The material entrapped in each sieve was examined microscopically and identified. Due to the lack of a boat, only nearshore samples could be obtained. However, the relatively small size of most of the sampled bodies of water suggests that the results accurately reflect the flora and fauna of the lakes and streams.

The distortion of fluvial and lacustrine beach sediments and the elevations and positions of the lacustrine sediments were analysed in order to assess the amount of glacio-isostatic depression and its duration. The method employed was that of Catto et al (1980, in press), as described in the "Isostatic Recovery" section.

B) Laboratory

Initial laboratory investigations centered on the sedimentological, palaeontological and chemical analysis of eight cores provided by the Alberta Department of Recreation and Parks from the immediate area of the DjOn-26 site. A complete summary of the stratigraphy of each of these cores is presented in Appendix A. Additional laboratory analyses were conducted on samples obtained through field investigations.

Textural analyses were conducted utilizing the hydrometer-sieve method (ASTM, 1964). Sieving of the sand-sized fractions was performed, and the results analysed using the techniques of Folk and Ward (1957). These results are presented in Appendix D. The mineralogies of the sand strata and the pebble lithologies of the gravel bands were also determined (Appendix E). Carbonate concentrations of the silt and clay units (Appendix F) were determined through the use of the Chittick method (Dreimanis, 1962).

The silt and clay units of each core were processed for pollen and spores using the method developed by the University of Alberta palaeoenvironmental group (as reported in Waters 1979), while the technique of Coope (1968) was employed to search for coleoptera. Phytoliths (Appendix O) were isolated using the method of Jones and Beavers (1964). Diatoms and molluscs were separated from the sediment after cleaning with dilute hydrogen peroxide, the molluscs manually and the diatoms by flotation in a 2.4 g/ml tetrabromethane-acetone mixture (Appendices L,M, and N).

Analysis of the carbon, nitrogen and extractable aluminum and iron present in the suspected humic soil horizons (Appendix J) was conducted according to the procedures of McKeague (1978).

The modified Walkley-Black method, semi-micro Kjeldhal method, and Pyrophosphate extraction method were the techniques employed, respectively. The chemical data obtained were used as aids in the classification of the soil horizons present within the cores.

The tephra present in the cores and samples from units exposed in the field was analysed to determine its phenocryst content, the amount of non-volcanic material, and the refractive index of the glass shards present (Appendices B and C). The glass fraction was separated from the remainder of the ash using the technique of Smith and Westgate (1969) as modified by Waters (1979). The refractive indices of the shards and phenocrysts were determined optically.

The electron microprobe technique (Smith and Westgate, 1969) is the most efficient method available for tephra chemical analysis, but it is an unsuitable procedure for most of the ashes exposed in the study region. The majority of the tephra strata were largely devitrified, and all older than Late Wisconsin were either completely hydrated or superhydrated. In addition, many of the shards contained vesicules, phenocryst inclusions, and other irregularites. Several ash bands within the cores contained only pumiceous material, as did some bedrock strata.

The only other techniques available for chemical analysis were those commonly employed for the analysis of silicate rocks. Since the tephra units were of potential importance for correlative purposes, some knowledge of their chemical composition was necessary. However, the complete analysis of the ashes would have consumed much more time than was available. Consequently, it was decided to determine the chlorine (as chloride), iron (as ferric oxide), sodium and potassium concentrations of the glass and pumiceous material. These elements were selected because of the relative ease with which the determinations can be made, and more importantly, because they have proven to be successful in differentiating among the various Late Wisconsin and Holocene tephra strata for which complete chemical analyses have been performed. In some instances, where extensive silicification of the ash had apparently recurred, the silica content was also determined.

The chloride concentration was determined by adding silver nitrate to the acid-digested samples, and subsequently weighing the silver chloride precipitate (Jeffery, 1975, pp. 191-192). The total iron content was determined as ferric oxide by titration with ceric sulphate and potassium dichromate solutions (Jeffery, pp. 293-295). The alkali metal concentrations were determined through flame photometric analysis of the alkali-sulphate complexes (Jeffery, pp. 82-83). The silica content for selected ashes was ascertained by reacting the sodium carbonate-fused sample with hydrofluoric acid and measuring the loss of weight (Jeffery, pp. 37-42). These results are presented as Appendix B.

Late Wisconsin and Holocene ashes found at Manyberries (Westgate, 1964), Mackay Creek (Westgate, 1972), Elkwater (Gryba, 1975; Westgate, personal communication, 1980), and Irvine (Westgate and Evans, 1978) which had previously been analysed using the electron microprobe technique were reanalysed using the procedures employed in this study, in order to check the accuracy of these techniques. The results indicate that the values obtained by the two methods are identical within the limits of sample variation and experimental error.

BEDROCK STRATIGRAPHY

The bedrock of the Western Cypress Hills region exerts a strong influence on both the composition and texture of the glacigenic sediments of the area. In addition, bedrock-derived colluvium is present in many areas, and must be distinguished from glacigenic material in order to properly describe the Quaternary stratigraphy. For these reasons, a brief review of the exposed pre-Quaternary stratigraphy of the region is in order. The system of nomenclature employed is that developed by Furnival (1946) in the Cypress Lake area of Saskatchewan. Table 1 compares the terminology employed by several researchers in the study region and surrounding districts for the Upper Cretaceous strata.

The oldest unit exposed in the study region is the Upper Cretaceous Alberta Formation, a dark grey marine shale unit with minor lensose sandstone and siltstone and sporadic bentonite beds. Within the study region, this formation outcrops only at Eagle Butte (Section 32, Tp. 8, R. 4, W. 4th) where a structural disturbance has resulted in a vertical upward displacement of the unit in excess of 1000 m (Russell and Landes, 1940). No sandstone, siltstone, or bentonite beds are present in the section at Eagle Butte.

The Pakowki Formation, a nearshore marine sequence of sandy and silty shales, is exposed in the southwestern corner of the study region in the vicinity of Aden. It is also present in both the

TABLE 1

TABLE OF FORMATIONS

	Williams & Dyer 1930	Russell & Landes 1940	Furnival 1946	Montana	Tozer 1956 Red Deer R.	Tozer 1956 South Plains
Tertiary		Cypress Hills	Cypress Hills			–
	Ravenscrag	Ravenscrag	Ravenscrag	Ft. Union	Paskapoo	Porcupine Hills
Upper Cretaceous			Frenchman	Lance Hell Creek	Upper Edmonton	U. Willow Cr. Lower Willow Creek
	Whitemud	Whitemud	Battle Whitemud	Fox Hills	Lower Edmonton	St. Mary River
	Estevan	Eastend	Eastend			
	Fox Hills	Blood Reserve				Blood Reserve
	Bearpaw	Bearpaw	Bearpaw	Pierre Bearpaw	Bearpaw	Bearpaw
	Belly River	Oldman Foremost	Belly River Oldman Foremost	Judith River	Belly River	Belly River
	Pakowki	Pakowki	Lea Park Pakowki	Claggett	Lea Park	Pakowki
	Milk River	Milk River	Milk River	Eagle		Milk River
	Colorado	Alberta	Alberta	Colorado	Alberta	Alberta

Milk River and Pakowki Coulee canyons. Russell and Landes (1940) informally divided the Formation into a lower silty grey marine shale and an upper offlap sequence of sandy shales and interbedded sandstones. Bands of bentonite, believed to be correlative to those noted by Williams and Dyer (1930) and Russell and Landes (1940), were found by the author in several exposures in Tp. 2, R. 9 and 10, W. 4th m. Examination of these bentonites using binocular and petrographic microscopes revealed that no glass shards were present.

The Foremost Formation is exposed in the northwestern portion of the study area. It is a nearshore estuarine sequence of grey to yellow sandstones, grey shales, and lignite. Mineralogically, the sandstone units are predominantly quartz and feldspar, with accessory apatite, biotite, chlorite, muscovite and zircon (Stewart, 1919 ; Williams and Dyer, 1930). The mineralogy of the shale units is dominated by montmorillonite and chlorite. Both lithofacies are calcareous, mainly due to the presence of calcite cement. Bentonite beds are common in the formation to the east of the study area (Furnival, 1946), but none were observed by the author or other investigators within the study region. Despite the extent of the Foremost Formation in the area, exposed sections of these strata are rather uncommon.

The Oldman Formation, a series of interbedded pale buff deltaic sandstones and shales, is exposed to the northwest and south of the Cypress Hills. Exposures are plentiful in the Manyberries-Bain area, and in the region south of Irvine and Walsh. The relative thickness of shale within the formation increases towards the east. These shale units are predominantly of montmorillonitic composition, while the sandstones are quartz-rich and contain between 10 and 20% clay minerals, mainly montmorillonite (Williams and Dyer, 1930; Furnival, 1946). The heavy mineral assemblage is dominated by biotite, with accessory muscovite, chlorite, apatite, garnet, magnetite and sphene (Williams and Dyer, 1930; Westgate, 1964). Three distinct bentonite beds were noted: in L.S.D. 3, Sect. 35, Tp. 4, R. 5, W. 4th (Crockford, 1951); and in L.S.D. 14, Sect. 20, Tp. 3, R. 3. W. 4th (Russell and Landes, 1940). All of these units proved to contain glass shards and fragments. Due to the age of the ash layers, all of the shard material shows evidence of severe weathering, and is totally divitrified and dehydrated. Throughout the upper Cretaceous succession in the region, graduation of pure volcanic ash beds into bentonitic strata is common, as was initially documented by Sanderson (1931). Chemical and mineralogical analyses of the Oldman ash strata are presented in Appendices B and C, respectively.

A dark grey marine shale, the Bearpaw Formation, rings the periphery of the Cypress Hills. Good exposures are found in the Manyberries-Bain badlands, and in the valleys of Ross and Mackay Creeks in the Irvine-Walsh area. None of the exposures are complete sections, however. Estimates of the thickness of the Bearpaw Formation range from 160 m (Williams and Dyer, 1930) to 325 m (Crockford, 1951).

These estimates are heavily dependent upon the choice of stratigraphic boundaries for the Formation, a matter which has been of some controversy amongst the various researchers.

The shale is composed of approximately 70% montmorillonite, 17-25% illite, and 5-10% chlorite (Byrne and Farvolden, 1959). Sandstone beds are present, but are rather discontinuous in nature with the exception of the Belanger and Oxarart members (Russell and Landes, 1940; Furnival, 1946). In these sandstone lenses, elliptical concretions of calcite formed around fossil fragment nucleii are quite common. Most of these concretions do not exceed 3 cm in diameter, and may be readily mistaken for limestone pebbles.

Abundant bentonite beds are present throughout the vertical extent of the Bearpaw Formation. Russell and Landes (1940) listed ten bentonite units from a series of exposures in the Manyberries-Bain badlands (TP. 4, R. 4 and 5, W. 4th). Furnival (1946) recorded 13 beds along Woodpile Creek, Sask., to the east of the study area (Tp. 1, R. 27, W. 3rd), and 26 beds along adjacent Boxelder Creek. Crockford (1951) recognized 32 bentonite units throughout the extent of the western Cypress Hills area, while Byrne and Farvolden (1959) noted 15 in a similar composite section. The differences in the number of beds observed illustrate the difficulties of correlation in an area characterised by a low density of outcrop, as well as the discontinuous nature of the units. Although attempts have been made to correlate individual bentonite strata across the study area (eg. Russell and Landes, 1940), such efforts are hazardous and prone to error.

The bentonites vary in colour from purple to grey to white to yellow to olive green, and also differ widely in purity. A common feature is the presence of gypsum or selenite crystals, formed by groundwater percolation through the strata. Appendix B presents chemical analyses of the glass shards and fragments present in several bentonite beds, while Appendix C lists the mineralogic composition of these sediments. The differences noticeable in both chemistry and mineralogy suggest that the Bearpaw bentonites are the products of several distinct provenances, both geographically and chronologically. In addition, observed variations in colour, shard habit, and degree of decomposition, as well as the stratigraphic relationships of the bentonite beds, suggest that many of these strata are the products of tidal and marine current reworking. This would aid in explaining the lateral non-persistence of most of the Bearpaw bentonites.

The Eastend Formation, an interbedded complex of estuarine grey shale and buff to grey sandstone, overlies the Bearpaw Formation immediately surrounding the Cypress Hills. The Formation's sandstones are dominantly quartz and feldspar, with associated calcite, biotite, chert, and magnetite (Stewart, 1919; Westgate, 1964), while the shale members are predominantly montmorillonitic. The low concentration of hornblende in the sandstone units is especially noteworthy.

Thin, discontinuous bentonite beds are commonly found in the Eastend Formation. Crockford (1951) recorded five bentonite strata in an exposure located in L.S.D. 8, Sect. 31, Tp. 7, R. 3, W. 4th meridian. Examination of these beds by the author revealed many chemical and mineralogical similarities to the bentonite units of the underlying Bearpaw Formation, suggesting either a similar provenance or reworking of the Bearpaw beds. The estuarine nature of the other members of the Eastend Formation would seem to support the second alternative.

The Whitemud Formation is poorly exposed at Eagle Butte, along the southern fringes of the Cypress Hills, and along their northeastern flank. It is a series of fluvial sandstones and shales and bentonite beds, all of which are interstratified in a complex manner. The fluvial sediments are composed dominantly of orthoclase, with accessory muscovite, chlorite, rutile, tourmaline, and zircon (Irish and Havard, 1968). In the Cypress Hills region, the Formation is depleted in carbonate in comparison to exposures west of the Sweetgrass Arch. The bentonite beds within the Formation are very much less laterally presistent than those of the Bearpaw Formation (Williams and Dyer, 1930; Byrne, 1955). Crockford (1951) noted three exposures of Whitemud bentonite (L.D.S. 5, Sect. 26, Tp. 8, R. 1; L.S.D. 8 and 15, Sect. 31, Tp. 7, R. 3, all W. 4th), while Furnival (1946) failed to observe any in the Cypress Lake area of Saskatchewan. Chemically, the Whitemud bentonites are rich in chloride and poor in potassium, (Appendix B). The heavy mineral assemblage is dominated by zircon, while both hornblende and clinopyroxene are conspicuously absent (Appendix C).

The Battle Formation is a series of bentonite, bentonitic shale, and tuff beds discontinuously exposed above the Whitemud Formation in areas where the latter outcrops. The bentonitic shales vary in colour from dark black to greenish grey, and are predominantly composed of montmorillionite. The strata thicken to the east, and were first given formational rank by Furnival (1946).

Of the numerous tuff and bentonite beds reported from the formation, the most significant and areally widespread is the Kneehills Tuff. Exposures of this unit have been reported over a broad expanse of southern and east-central Alberta (Sanderson, 1931; Crockford, 1951; Ower, 1960; Irish and Havard, 1968; Binda, 1969). Potassium-argon dating of biotite from associated bentonites suggests an age of 66 million years (Folinsbee et al, 1965), placing it within the Upper Cretaceous. The stratum is pale grey to mauve, vuggy, and well-indurated due to a high degree of silicification (Sanderson, 1931). Mineralogically, the tuff is characterised by the presence of magnetite, ulvospinel, zircon, and iron-rich reddish-brown biotite (Irish and Havard, 1968). Rutile, pyrite, and tourmaline are often present in minor quantities. The results of chemical analyses of the devitrified glass shards obtained from several of the bentonite strata in the Battle Formation are characterised by very high concentrations of silica, in two instances exceeding 90%. It is probable that the original shard chemistry has become altered during the silicification process undergone by the unit as a whole.

The Frenchman Formation, a fluvial sandstone, forms the base of the Cypress Hills escarpment in the study region. Mineralogically, it is a quartz-rich subgreywacke, with a diverse heavy mineral assemblage dominated by apatite, biotite, clinopyroxene, sphene, zircon, epidote, and andradite, alamandite, and gossularite garnets in the study area (Westgate, 1964; Rahmani and Lerbekmo, 1975). Several thin bentonite beds are present in the formation in other areas, but none have been observed in the study region.

The Ravenscrag Formation, of Palaeocene age, forms the majority of the thickness of the Cypress Hills escarpment. It is composed of two sandstone units, a lower grey facies and an upper buff facies, with interbedded silts, pink, red, green, grey, and black clays, and bentonite beds, lenses, and pods (Williams and Dyer, 1930). The mineralogy of the sandstone units resembles that of the underlying Frenchman Formation. The highly lensose nature of the bentonite present in Ravenscrag strata, in addition to the close chemical and mineralogical resemblance of many occurences to underlying bentonitic strata suggest that the material has been largly derived from the Battle, Whitemud, and Bearpaw Formations.

Capping the Cypress Hills plateau are the quartzite gravels of the Cypress Hills Formation. In addition to quartzite, the gravels also contain andesite, chert, and trachyte porphyry pebbles. The heavy mineral assemblage of the sandy matrix is dominated by magnetite, ilmenite, zircon, garnet, epidote, and sphene (Westgate, 1964; Jungerius, 1966). Most of the garnet is andradite and grossularite. Hornblende is present as trace amounts in most samples. The Cypress Hills Formation is assigned an Oligocene age on palaeontological grounds (Russell and Landes, 1940), and is considered to be a fluvial deposit formed by a stream whose provenance was the Precambrian Belt Series and Palaeozoic limestone exposures in northwestern Montana and southwestern Alberta (Alden, 1924; Vonhof, 1965).

QUATERNARY DEPOSITS AND LANDFORMS

In this section, the Quaternary deposits and landforms recognized and investigated by the author will be discussed. In order to facilitate discussion, the sediments and features have been divided into several genetic catagories: glacial, including tills and glacially-produced colluviated material; glaciofluvial, including outwash gravels and sands, eskers, and crevasse fillings; lacustrine; fluvial; and aeolian, including loess, sand dunes, and volcanic tephra. Within each chapter, discussion of the sediments and features is arranged in the chronological order of their formation. Correlation of the sediment types to each other is discussed both within the individual deposit and landform chapters and in the Conclusion (Quaternary History and Chronology).

GLACIAL DEPOSITS AND LANDFORMS

Glacial till forms the surface sediment over approximately 70% of the western Cypress Hills region. Deposits formed during three distinct stadial events are exposed at the surface. The sediments also indicate that a number of minor advances and retreats occurred during the major stadials. These till sheets can be correlated to and differentiated from each other on the basis of stratigraphic position, pebble lithology, fabric pattern, and relationship to geomorphic features such as drumlins and moraines. In addition, several till deposits apparently representing previous glaciations are exposed in river valleys and can be recognized in drilled wells and boreholes. These glacial deposits, their related landforms, and the evidence for each stadial event will be discussed in chronological order.

a) Early Tills

The thick Quaternary sections exposed on the South Saskatchewan and Oldman Rivers contain till units which are not recognized on the surface anywhere in Southeastern Alberta. Other old tills, which may be correlative to those in the river sections, have been discovered in boreholes drilled to the north and west of the study area (D. Proudfoot, University of Alberta, personal communication, 1980). No definite stratigraphic or compositional parameters have yet been established for these units, making reliable correlation over even short distances extremely uncertain at present (Stalker, personal communication, 1979).

Tills believed to be older than the oldest surface drift sheet are exposed in sections along Mackay and Canal Creeks, and along Chin Coulee in the vicinity of Foremost. The sediments vary widely in composition and texture, and no unit can be correlated between outcrops with reliability. Fabric analysis of pebble orientations was not possible, except at a single locality along

Mackay Creek (W-53), due to a general paucity of suitable clasts. No horizons of value for correlative purposes are present between any of the subsurface till units, and no faunal or floral material is interbedded with them. The subsurface units are not found in the zone where the oldest surface till is exposed. Consequently, there is a possibility that some or all of these units simply represent different facies of the oldest surface till sheet.

At one locality along Mackay Creek (W-53), the lowest till exposed overlies a contorted sand unit with interbedded silt and gravel lenses. This sediment has previously been correlated with the lacustrine sediments exposed at Wolf Island (Westgate, 1964, 1968). The presence of contorted moderate-angle crossbedding defined by hornblende, magnetite, and other heavy minerals, and the modal medium-sand texture suggest that this unit is a sandur deposit which was deformed upon being overridden by the advancing glacier responsible for its formation. The absence of floral and faunal matter from the deposit suggest rapid deposition of the sediment under rigorous climatic conditions. Similar successions have been noted in areas where glaciers currently are active (Okko, 1955).

No conclusions can be drawn with respect to the age of the early till units. The vertebrate faunal successions present in the Wellsch Valley (Stalker and Churcher, 1972) and Medicine Hat (Stalker, 1969a) deposits indicate that glaciation has been a factor in the region's geological development since the Nebraskan glacial.

Consequently, the tills could be virtually any age between Nebraskan and the inferred age of the oldest surface till.

b) Phase A Glaciation

The oldest surface drift is here assigned to the Phase A Glaciation. This material corresponds to the Elkwater drift of Westgate (1965).

Most of the evidence indicating the existance of the Phase A glaciation consists of the distribution of erratics around the Cypress Hills Plateau. The highest elevation at which Canadian Shield material has been found is 1450 m, at several locations south of Elkwater (E-110). The elevation of the erratic limit decreases gradually to the east, reaching 1330 m near Fort Walsh, Saskatchewan (FW-211). The erratic limit also decreases in elevation to the south along the western escarpment, from 1350 m (PL-105 m) at the northwest corner to 1220 m at Thelma Creek (ML-224 d). The highest elevation noted along the southern flank of the plateau was 1250 m (FX-276 aa). Figure 5 depicts the maximum erratic limit in the Elkwater area as discovered by the author. This line represents the minimum possible extent of glaciation. Undoubtably, the distribution of erratics has been altered to some degree by colluviation and alluvial transport, while other Canadian Shield materials lie beneath thick blankets of postglacial loess. The complex pattern of salients and re-entrants depicted on the southern

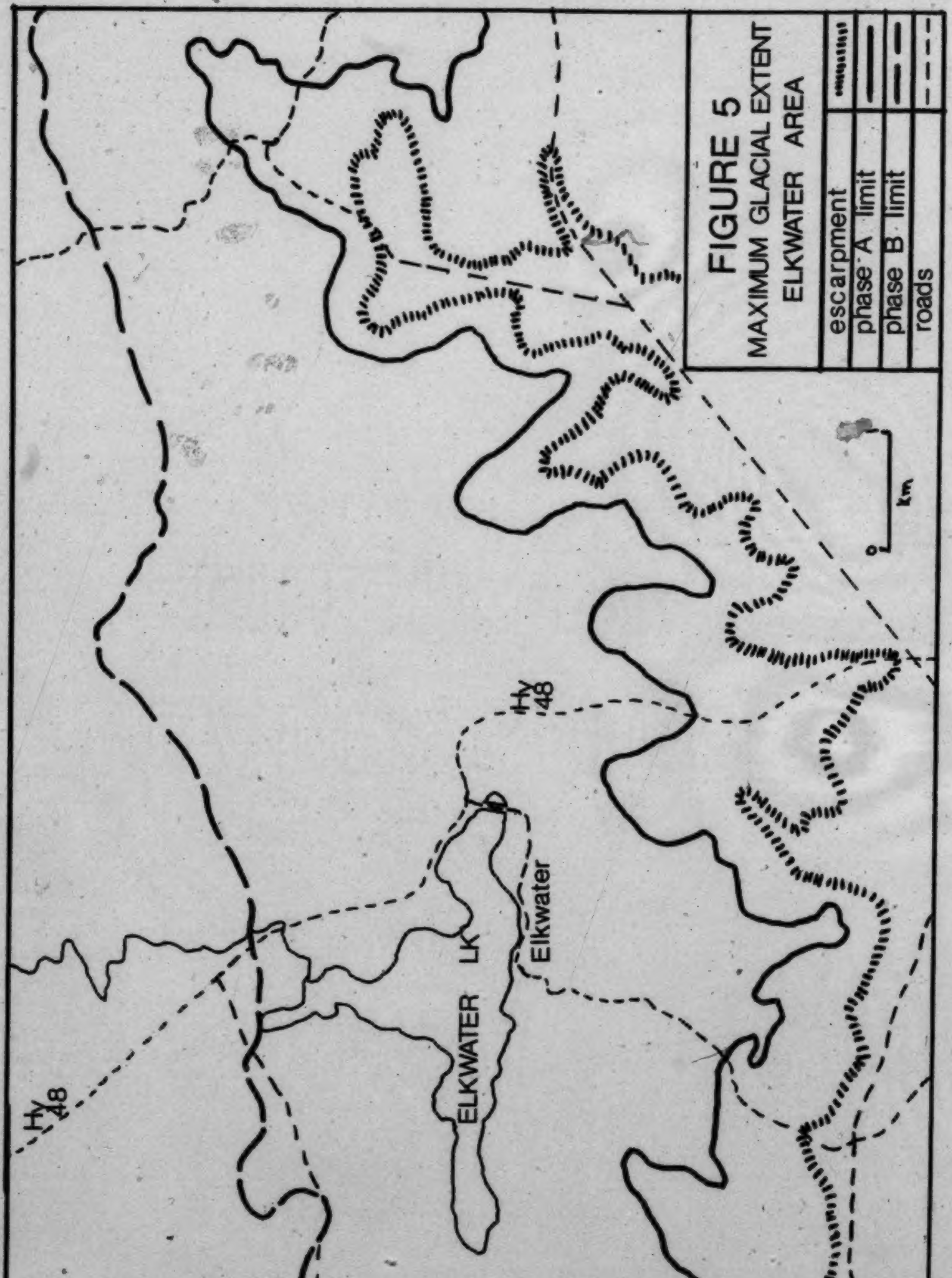


FIGURE 5
MAXIMUM GLACIAL EXTENT
ELKWATER AREA

escarpment
phase A limit
phase B limit
roads
0
km
N
Hy 48
Hy 48
ELKWATER LK
Elkwater

slope of the plateau therefore probably does not represent the actual nature of the ice front.

No exposure of Phase A till adequate for stratigraphic or compositional definition of the unit exists. The only surface sediment definitely attributable to Phase A is a mixture of till and colluviated material at location ML-5, along the eastern side of Medicine Lodge coulee (Appendix H). Although textural and compositional details of this sediment were determined, they are not considered to be characteristic of the drift sheet. Figure 6 illustrates the similarity of the mineral compositions of the till-colluvium mixture exposed at ML-5 and the Cypress Hills Formation. The absence of a "type section" makes correlation with subsurface units and those exposed in river-cut bluffs to the north impossible.

The age of this Phase is uncertain. Since it represents the most extensive glaciation, it has been correlated to the highest advance recorded at Del Bonita, Alberta (Stalker, 1965) and the most southerly ice front position in Montana and North Dakota (Colton _et al_, 1961; Lemke _et al_, 1965). Throughout northern North America, the continental glaciers are considered to have reached their maxima during either the Kansan or Illinoian glacial. The southernmost deposits in Kansas (Dort, 1972), Nebraska (Bayne, 1968), and Illinois (Willman and Frye, 1970) are believed to have been formed during these glacials. It can be inferred, therefore, that Phase A probably represents one of these events. In the absence of more physical data, this conclusion must remain purely speculative.

FIGURE 6. Mineralogy, Phase A Sediments

The figure illustrates the similarity between the till/colluvium mixture at locality ML-5, the Cypress Hills Formation, and the Flaxville gravel. For comparison, a subsurface sample correlated to Phase A, the till exposed at locality W-53 is included.

LEGEND

C........ Cypress Hills Formation (mean of 6 samples)
F........ Flaxville Gravel (mean of 4 samples)
ML 5..... Sample ML 5
W 53..... Sample W 53
Fspr..... Feldspar
H. M..... Heavy Minerals
Hblde.... Hornblende
Gnt...... Garnet (mostly Grossularite)
Mgn...... Magnetite

The diagrams show the proportion of each mineral present relative to the sum of the three triangle members.

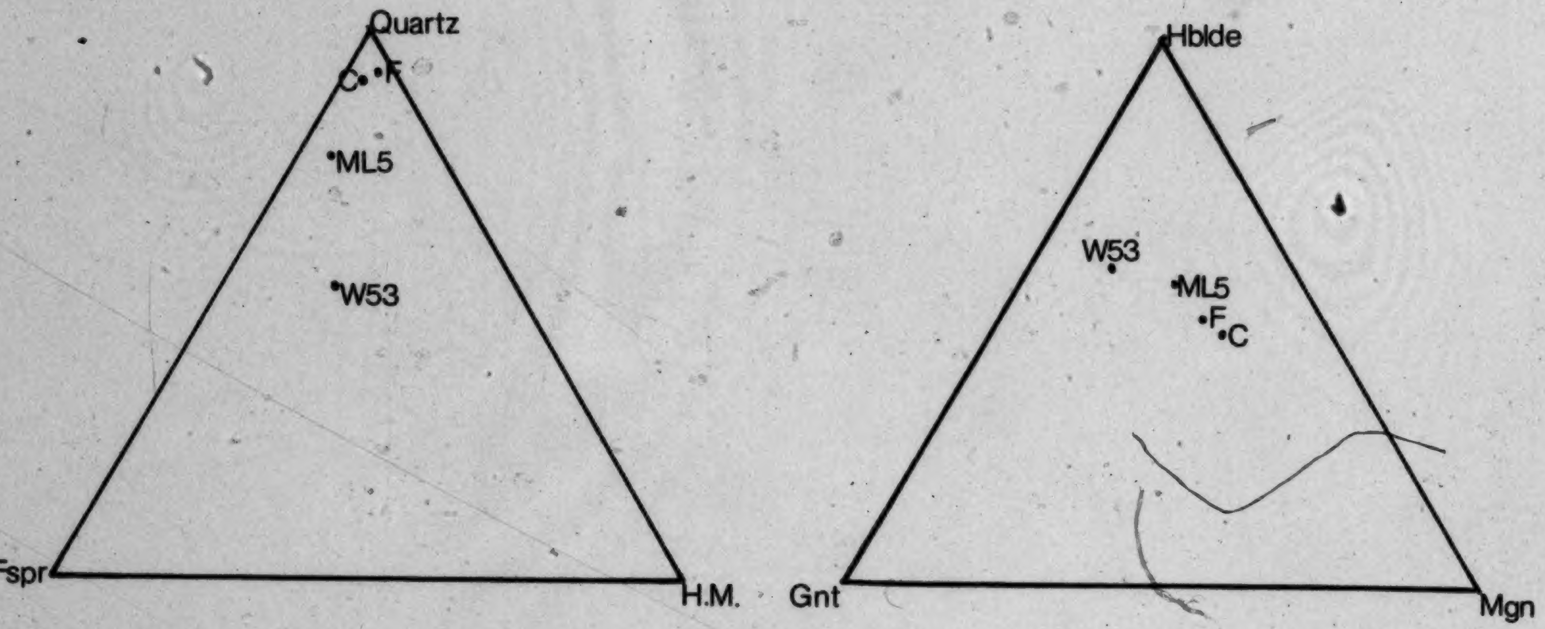


FIGURE 6. MINERALOGY, PHASE A SEDIMENTS

c) Phase B Glaciation

The Phase B Glaciation is the oldest event which produced till currently exposed at the surface. Phase B sediments cover the region south of the Etzikom moraine, with the exception of the Cypress Hills Plateau and a ring-like area around it.

Most of the area of outcrop of these tills coincides with the area where the Bearpaw shale is covered only by Quaternary units. Consequently, the glacial sediments are composed largely of material derived from this Formation. The tills are dark grey (2.5 YR 4/1 m) and are clayey in texture. The heavy mineral suites of the Bearpaw Formation and the sediments are essentially identical (Figure 7). The nature of the bedrock limited the number of pebble-sized clasts capable of surviving glacial transport. Over 90% of the pebble-size clasts in all Phase B exposures originated either from the Canadian Shield or its flanking Palaeozoic carbonate belt (Table 2). The absence of clasts from the Eastend sandstone suggests that this Formation had been totally removed from the area prior to the onset of Glacial Phase B.

Subsurface tills believed to be correlative to Phase B occur in the Mackay Creek, Irvine, and Little Plume areas. These correlations are based entirely upon the stratigraphic position of these units beneath the surface exposures of Phase C tills. No mineralogical or textural correlations can be made because these sediments overlie either the sandy Oldman Formation or tills derived largely from this Formation.

PLATE 1. Phase A Till-Colluvium Exposure, Locality ML-5. A mixture of material produced during the Phase A event overlies cross-bedded Ravenscrag sandstone at this site. The till-colluvium mix is capped by a thin loess layer.

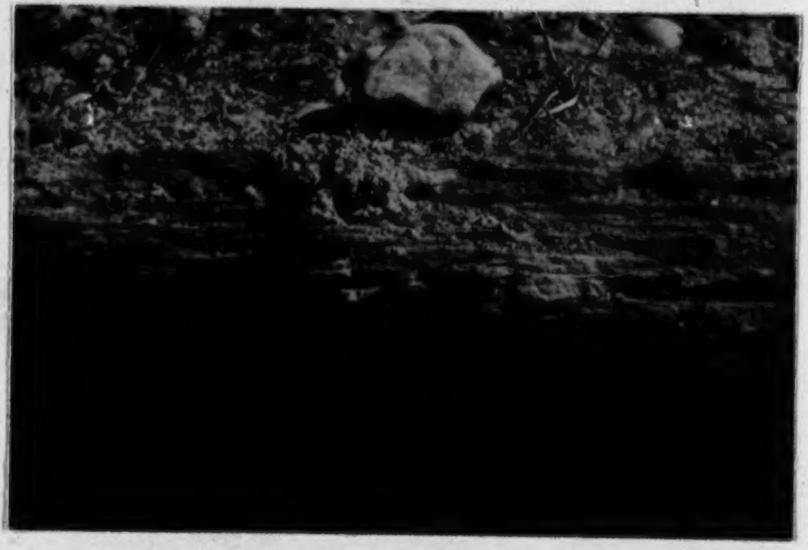


PLATE 2. Phase B Till containing large clast of Oldman Sandstone, Locality W-53.
The clast was probably detached from the bedrock as a result of glacial thrusting and shearing.
Scale: 1:25

COLOURED PICTURE

FIGURE 7. Mineralogy, Phase B Till

The figure compares the mineralogies of the Phase B till and the Bearpaw Formation.

LEGEND

Gnt.......... Grossularite Garnet
Hblde........ Hornblende
Mgn.......... Magnetite

The diagram shows the proportion of each mineral present relative to the sum of the three triangle end-menbers.

FIGURE 7

MINERALOGY

PHASE B TILL

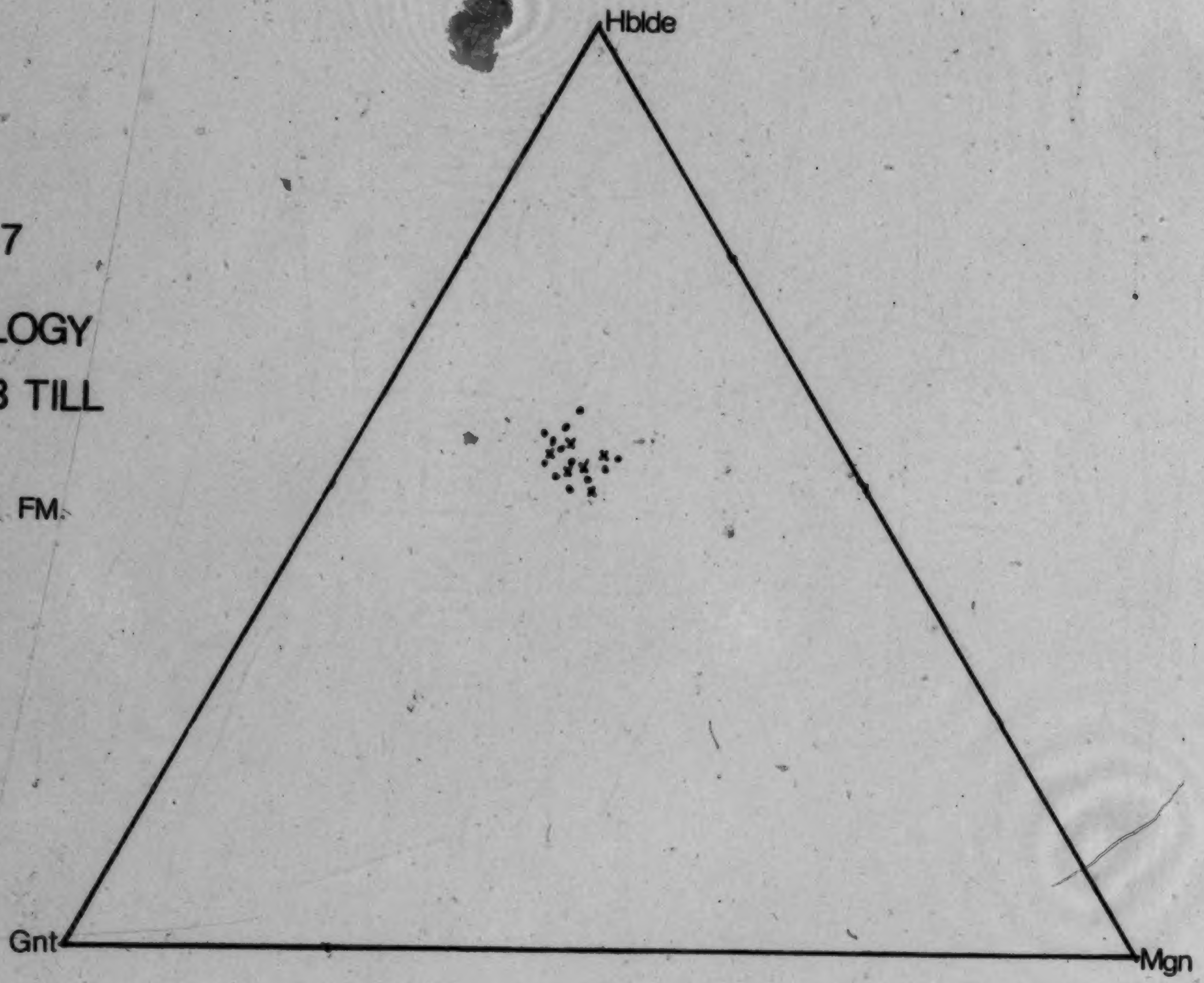


Table 2

Pebble Composition of Phase B basal tills

Sample°	Canadian Shield Crystallines %	Palaeozoic Carbonates and Clastics, %	Bearpaw	Other Local
MB-7	55	40	5	-
R-24 till 2	57	39	3	1*
R-33	56	42	2	-
WH-62	63	35	2	-
WH-63	60	40	-	-
WH-70	58	39	3	-
WH-73	60	39	1	-
OF-74	54	44	2	-
OF-75	50	46	2	2*
MR-78	52	43	3	2**
CC-80	57	36	4	3**
BH-122a	55	41	1	3'
LP-125	62	32	4	2*
LP-129	60	33	4	3"
T-132	57	43	-	-
T-133	56	38	3	3**
BH-134	60	40	-	-
T-148	49	44	6	1*
MB-175	56	40	3	1*
MB-222	51	46	1	2*
GV-238	58	42	-	-
WH-243	61	38	1	-
JD-279	59	38	2	1'

* Oldman Formation
** Oldman and Foremost Formations
' Ironstone concretions; source indeterminate
" Oldman Formation and ironstone concretions, source indeterminate

° Localities given in Appendix G.

As a result, there is little similarity between the sub-surface tills and those exposed overlying the Bearpaw shale.

Although several till layers and lenses have been correlated to Phase B, the entire glacial succession can be divided into two facies. The majority of the units were formed at or near the glacial sole. These tills are dense, compact, and clay-rich. They were found to display strongly-oriented fabric patterns at those localities where sufficient pebbles for analysis were available (Figure 8). The presence of sand lenses and minor stratified zones in the tills suggests that these sediments were formed under conditions of basal ablation, and therefore they can be described as basal melt-out tills.

The second facies unit is present in the Manyberries-Bain area. Characterised by a high proportion of pebbles (mode 50%) and a sandy matrix, these sediments appear to be supraglacial ablation deposits. Their fabric patterns were not strongly oriented (Figure 9), and the low plunges of the pebbles suggest fluvial reworking. At several localities, the fabric orientation was found to conform with the topography of the till unit. Sand and clay lenses are commonly present also indicating that extensive reworking by running water has occurred.

In the Lake Pawkoki area, the ablation facies is easily differentiated from the basal facies through pebble lithologies, mineralogies, and textures. The composition of the ablation facies

FIGURE 8. Phase B Till Fabrics

The figure illustrates fabric patterns from typical to Phase B basal tills.

The data points, representing the trend and plunge of till clasts, are plotted on an equal-area (Schmidt) stereonet. These plotted points were analysed by determining the number which lay within counting circles representing 2% of the total area of the stereonet, and then expressing this figure as a percentage of the total number (50) of sample points. The diagrams are contoured to reflect the density pattern revealed by the counting circle determinations.

LEGEND

▨...... Area where 5% of clasts lie within counting circles

■...... Area where 10% of clasts lie within counting circles

150...... Preferred orientation of clasts

FIGURE 8 PHASE B TILL FABRICS

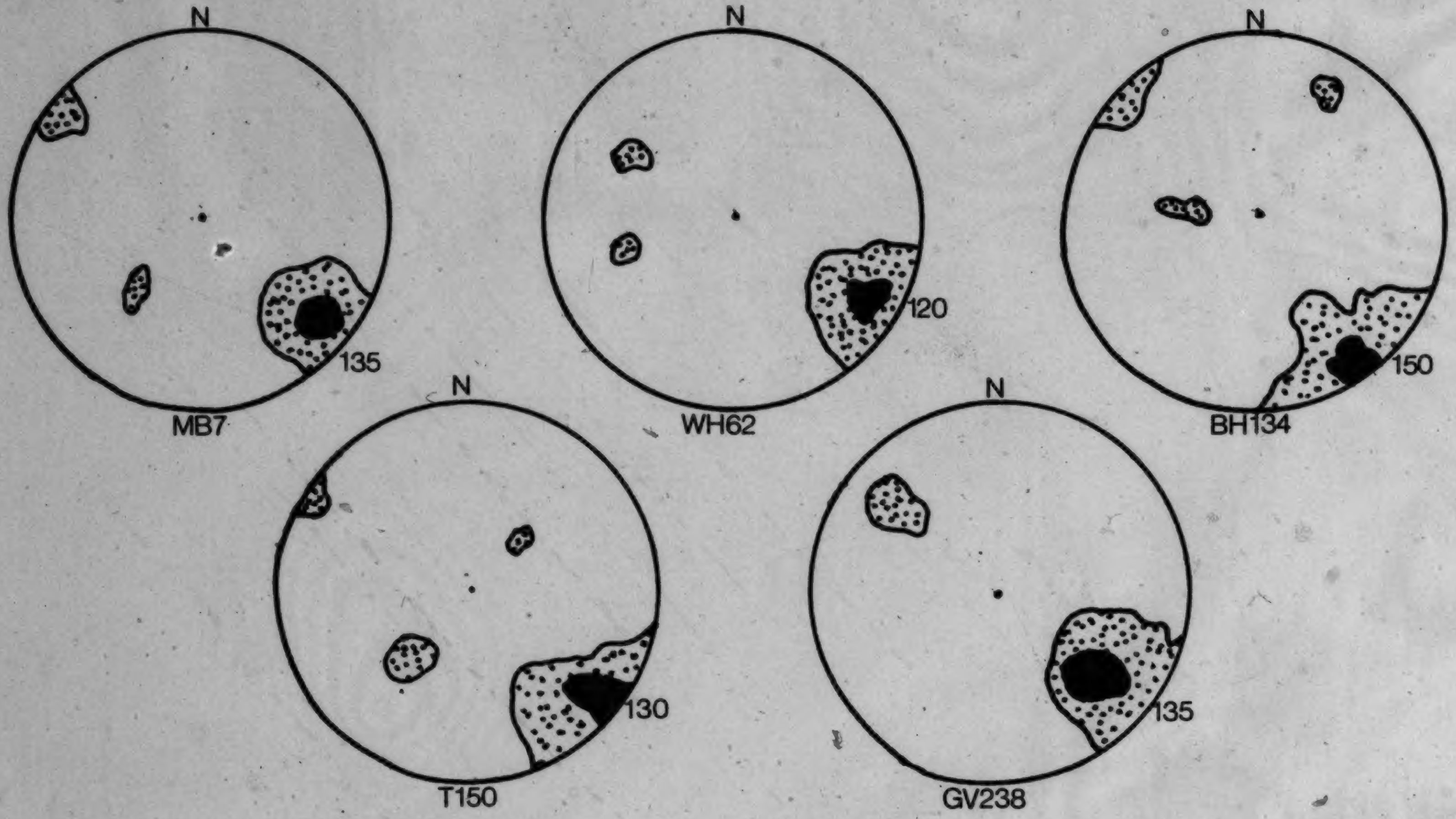


FIGURE 9. Phase B Ablation Till Fabrics

The Figure illustrates fabric patterns from typical Phase B ablation (supraglacial) tills. These sediments are characterised by random fabric orientations.

LEGEND

⊟...... Area where 2% of clasts lie within counting circles

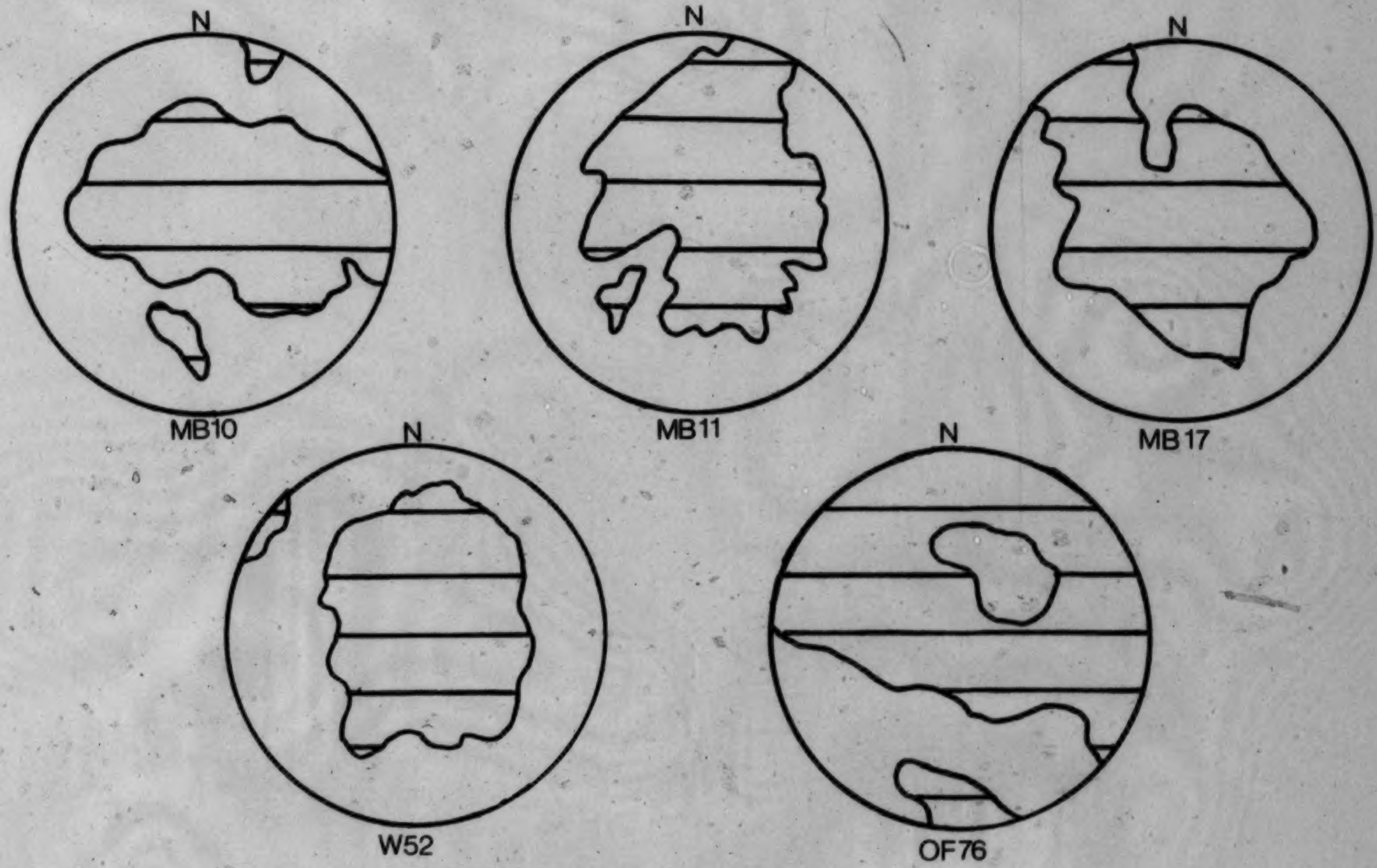

N
MB10
N
MB11
N
MB 17
N
W52
N
OF76

FIGURE 9 PHASE B ABLATION TILL FABRICS

is dominated by Precambrian material from the Canadian Shield, Paleozoic carbonates, and the Foremost Formation, while the basal facies contains clasts originating from the Oldman and Bearpaw Formations (Figures 10 and 11, Table 3). The surface transition between these tills occurs approximately along the subsurface transition zone between the Oldman and Bearpaw Formations. In the area north of Elkwater, the two facies are much more difficult to distinguish, primarily because the units are uniformly underlain by the Bearpaw Formation (Figures 12 and 13, Table 4).

Along the northern Cypress Hills escarpment, the maximum extent of the Phase B advance is marked by a prominent moraine extending from the provincial boundary west to Fly Lake. In Saskatchewan, an extension of this moraine is present north of Fort Walsh. The limit along the southern escarpment is delineated by the Green Lake moraine (Westgate, 1972). A second frontal position associated with a recessional event of Phase B can be recognized along the south bank of Middle Creek, where two small segments of a moraine are present (localities FX-258 and JD-277). This recessional phase may correlate to a small moraine exposed in the Robinson area. No other recessional positions can be recognized.

Along the western flank of the escarpment, the Phase B limit is denoted only by indirect means. Investigation of the mineralogy of colluviated material along the eastern slope of the Eagle Butte

FIGURES 10 - 18.

LEGEND

Cl......	Clay-sized particles
Cy......	Clay-Minerals
Fspr....	Feldspar
Fl......	Fluorite
Gnt.....	Garnet
H. M....	Heavy Minerals
Hblde...	Hornblende
Qtz.....	Quartz
Px......	Pyroxene
Sd......	Sand-sized Particles
Si......	Silt-sized Particles
Mgn.....	Magnetite

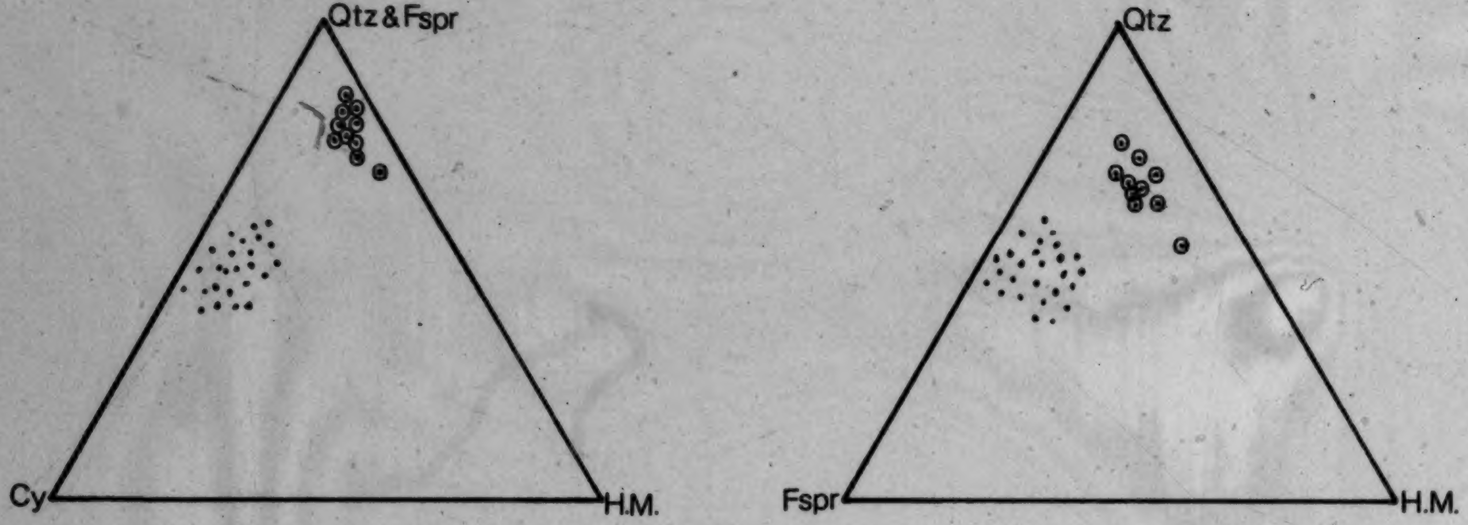


FIGURE 10 PHASE B TILL MINERALOGY, Manyberries Area

- BASAL
● SUPRAGLACIAL

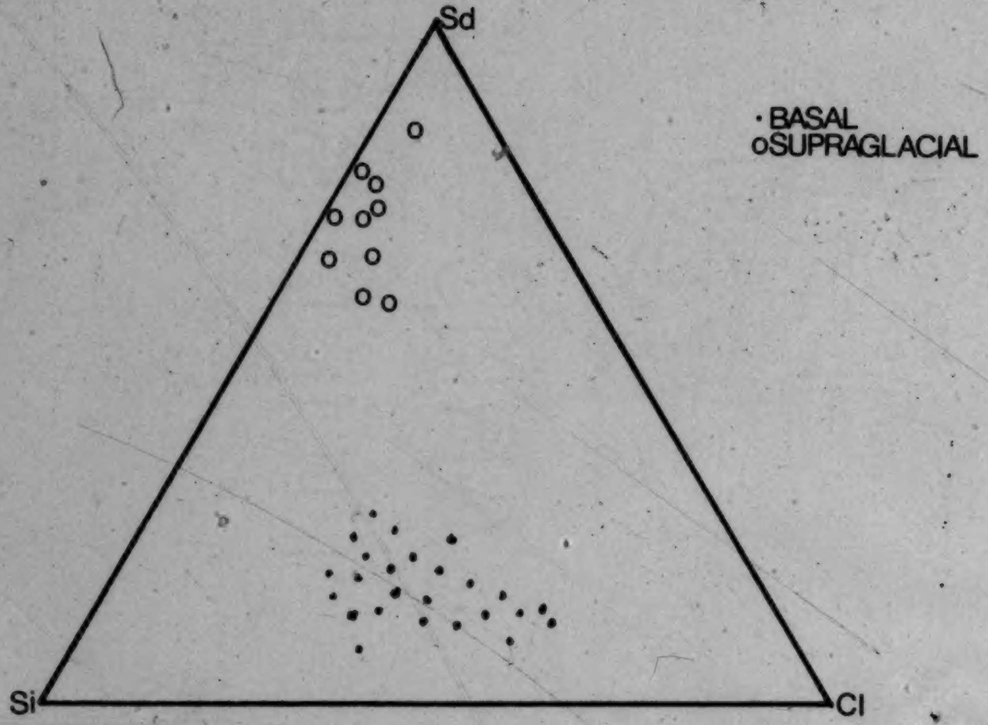


FIGURE 11 PHASE B TILL TEXTURE, Manyberries

Table 3

Pebble Composition of Phase B Tills, Manyberries Area

Sample°	Canadian Shield Cyrstallines and Palaeozoic Carbonate %	Oldman & Bearpaw	Foremost	Till Facies
MB-7	95	5	-	Basal
MB-8	94	6	-	"
MB-9	96	3	1	"
MB-175	96	4	-	"
MB-222	97	3	-	"
MB-232	98	2	-	"
MB-8	84	4	12	Supraglacial
MB-10	86	2	12	"
MB-11	88	-	12	"
MB-12a	93	-	7	"
MB-12b	84	-	16	"
MB-17c	100	-	-	"
MB-17d	90	2	8	"
MB-17d	93	1	6	"
MB-17e	94	-	6	"
MB-17f	96	1	3	"

°Localities given in Appendix G.

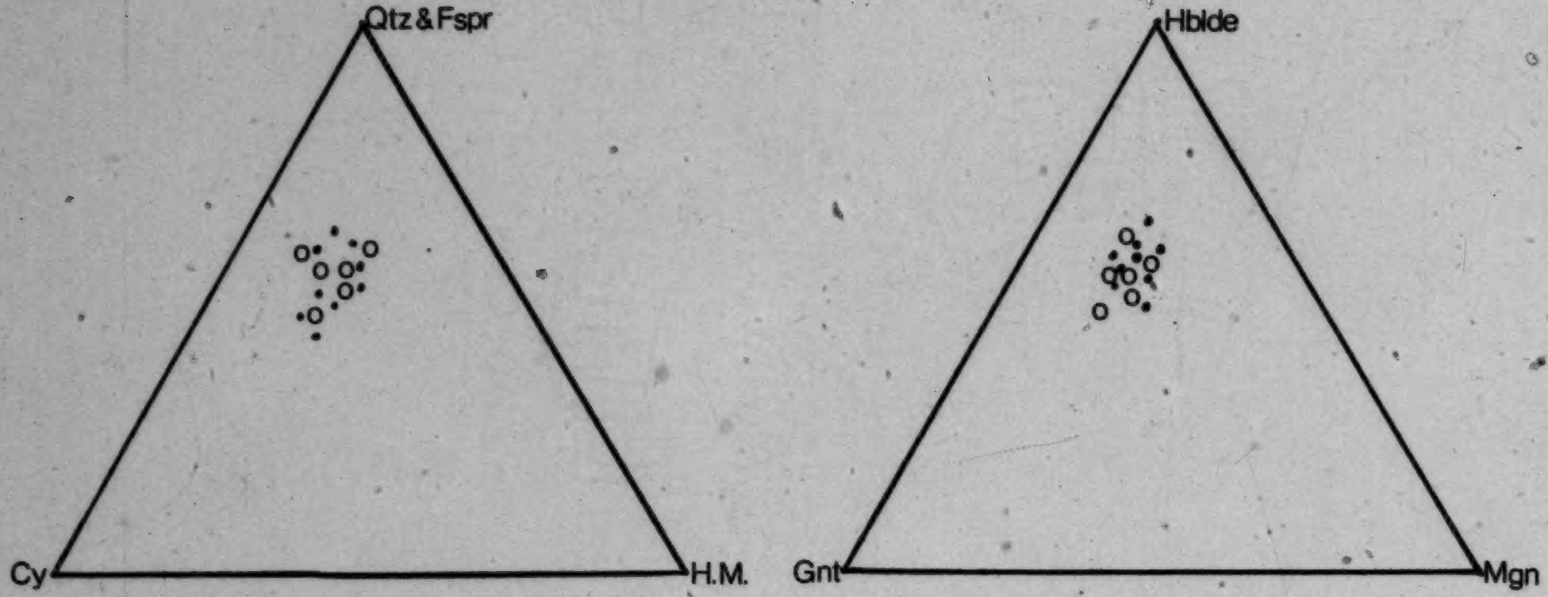


FIGURE 12 PHASE B TILL MINERALOGY; Irvine Area

· BASAL
o SUPRAGLACIAL

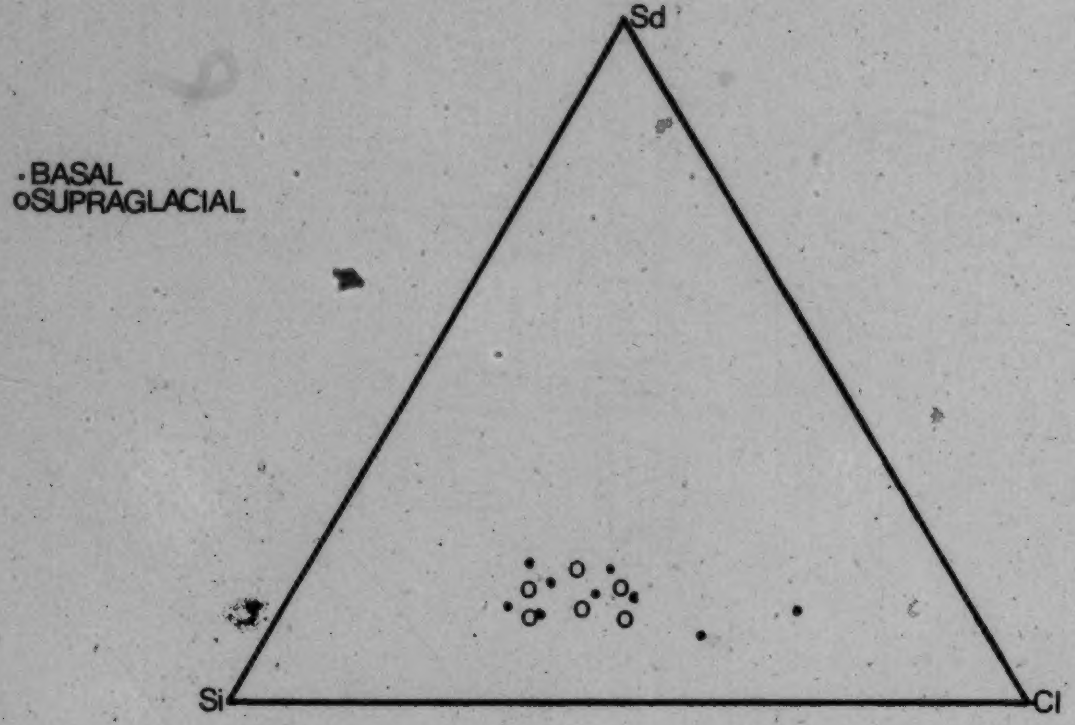


FIGURE 13 PHASE B TILL TEXTURE, Irvine Area

Table 4

Pebble Composition of Phase B Tills, north of Elkwater

Sample[o]	Canadian Shield Cyrstallines and Palaeozoic Carbonate %	Bearpaw %	Oldman & Foremost %	Till Facies
R-24 till 1	90	8	2	Basal
R-24 till 2	96	3	1	"
IR-31 till 3	90	10	-	"
R-33	98	2	-	"
W-52	98	2	-	"
W-53 till 1	95	2	3	"
W-53 till 2	98	1	1	"
W-54	96	3	1	"
R-36	99	1	-	Supraglacial
W-47a till 1	96	1	3	"
W-47a till 2	95	3	2	"
W-52	98	1	1	"
W-54	96	4	-	"
W-55	94	4	2	"

[o] Localities given in Appendix G.

escarpment (localities ML-18 and LP-142) revealed similarities between this material and that of the Fly Lake- Fort Walsh and Green Lake moraines. Consequently, the line of transition between this mineral assemblage, characterised by higher proportions of hornblende, magnetite, and grossularite garnet than those found in the area glaciated only during the Phase A event (as shown on Figure 14) is considered to be the limit of the extent of the Phase B glaciation. The limit of the Phase B glaciation thus follows the crest of the escarpment along the western side of Medicine Lodge Creek as it parallels the Cypress Hills' western escarpment, and then cuts obliquely across the coulee to connect with the Green Lake moraine.

Fabric analyses of the pebbles contained in the basal till units indicate that the direction of glacial flow was generally to the southeast, a conclusion substantiated by the presence of similarly-aligned flutings in the Onefour area. South of the Cypress Hills, the ice flow direction was east-southeast, as indicated by fabric analyses, with minor areas of northerly flow immediately adjacent to the escarpment margin. Figure 15 illustrates the pattern of the fabric analyses of the basal Phase B till units.

The Phase B glaciation as defined here encompasses both the Pakowki (Robinson) and Wild Horse (Green Lake) drift sheets of Westgate

FIGURE 14

COMPARISON OF
MINERALOGY,
PHASE A & B SEDIMENTS

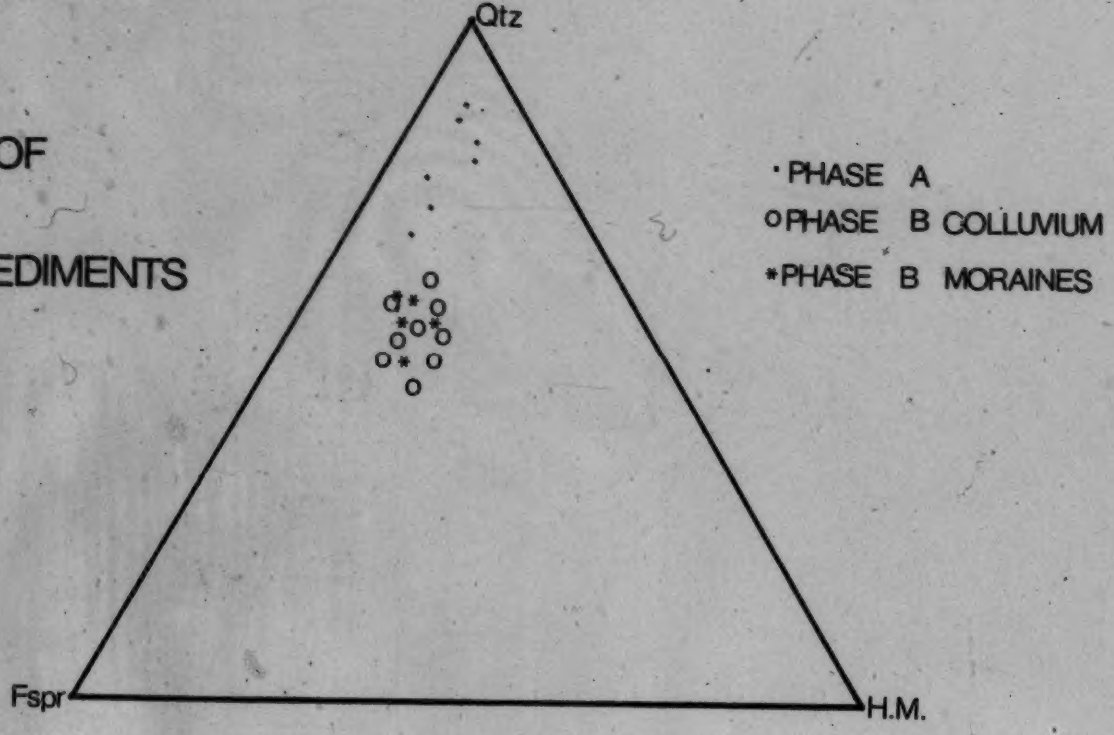


FIGURE 15

Phase B Fabrics

The Figure illustrates the fabric pattern of Phase B basal tills.

LEGEND

B...... Bain
E...... Elkwater
I...... Irvine
M...... Manyberries
O...... Orion
W...... Wild Horse

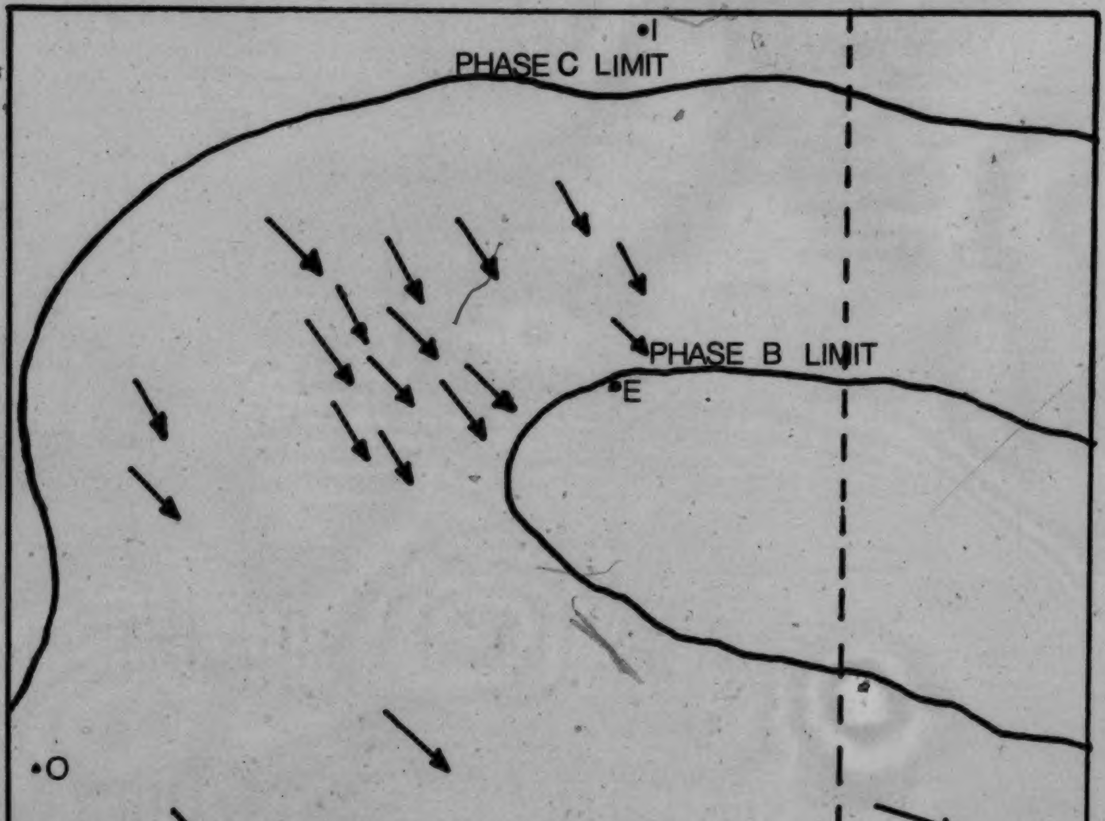

I
PHASE C LIMIT
PHASE B LIMIT
E
O
M
B
W
N
0 km 10
ORIENTATION

FIGURE 15
PHASE B FABRICS

PLATE 3. Basal and supraglacial ablation facies, Phase B till, Locality MB-8. Thrust plane contacts (dark bands) are present in the basal facies till. Note the abrupt contact between the facies, suggesting meltwater channelling and erosion. Scale: 1:25

PLATE 4. Thrust-faulted sand beneath Phase B Till, Locality IR-31. The alignment of the faults indicates that glacial movement was from the northwest.

COLOURED PICTURE

(1964, 1972). Westgate differentiated the tills on the basis of texture, pebble lithology, and geomorphic setting. The border of the Pakowki advance was defined as the Pakowki moraine, a series of arcuate ridges south of Lake Pakowki. This feature was linked to a minor moraine near Robinson, and was considered to represent a major ice advance.

The arcuate pattern of the ridges of this feature about a common centre (the main basin of Lake Pakowki), the fact that they are composed entirely of sandstone and shale, and the general thinness of the till cover in the area indicate a glaciotectonic rather than a morainic origin. In geomorphic form, they strongly resemble ice-thrust ridges as described by Kupsch (1962) and Moran (1971). Although repetition of the Oldman and/or Foremost strata cannot be unequivocably demonstrated, due to the absence of easily-recognizable continuous marker beds, the similarity of the lithologic sequence at several locations, notably CC-84 (a-k) and CC-184 (c-f) is striking (Figure 16). Each ridge is capped by a sandstone unit, which is either exposed at the surface or covered by less than 1 m of till. This stratigraphy suggests that thrusting occurred along sandstone-shale contacts, the less competant shale gliding over the sandstone. The thrusting activity would thus cause each shale bed to be displacing more than the underlying sandstone bed, producing an alternating sequence of resistant, slightly up-turned sandstone beds and intervening low shale areas. The relief produced in this manner would

FIGURE 16.

Sections, CC-84

The figure shows the repetition of bedrock strata in the area southeast of Lake Pakowki. The cause of this repetition is assumed to be glaciotectonic overthrusting. The uppermost sequence in sections CC-84 a, b, and d, is repeated three times; similar repetition is noted in sections g and j. A second sequence is also repeated in sections g and j. The increasing height of the thrust ridge towards the south illustrated in Figure 16 indicates that the direction of glacial advance was from the north. See text for further discussion.

LEGEND

□ Sandstone
■ Shale
▨ Till

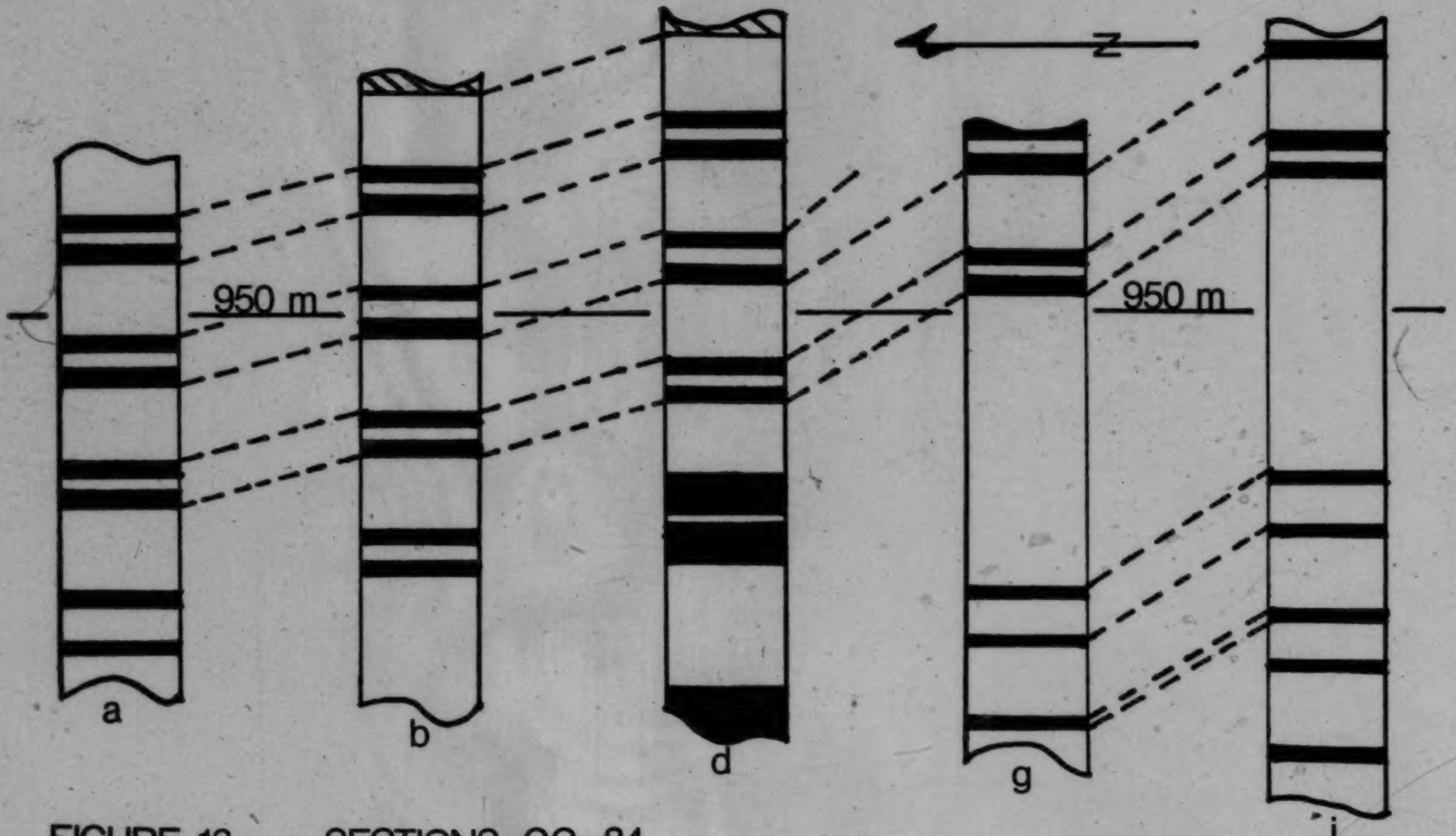

Z
950 m
950 m
a
b
d
g
j

FIGURE 16 SECTIONS, CC-84

VERTICAL SCALE 1 cm = 1 m
HORIZONTAL NOT TO SCALE

be further accentuated during ablation, as meltwater flowing along the ice front concentrated in the valleys and preferentially eroded the weakly-consolidated shale beds. Much of this bedrock material was probably derived from the area now occupied by the Pakowki Basin. A similar ice-thrust ridge pattern is present southwest of Onefour and east of Pinhorn: a portion of this was also mapped as a terminal moraine by Westgate (1964).

The distinctive characteristics noted for the Wild Horse and Pakowki tills by Westgate (1964) and Barendregt (1977) are the results of a change in bedrock lithology and supraglacial reworking by meltwater. The differing magnetic fabrics recorded for these two tills by Barendregt (1977) can be explained if it is remembered that such fabrics are produced by the orientation of particles in flowing water (Gravenor _et al_, 1973). Fabric produced by alignment of magnetic particles in an englacial or subglacial position can be reoriented by subsequent subaqueous reworking in a supraglacial evnironment. Barendregt's data are compatible with the supraglacial reworking hypothesis, as are the textural and sedimentological data.

The Phase B glaciation is correlated to Phase 1 of Christiansen (1979) and Lemke _et al_, (1965), on the basis of end moraine positions and till characteristics. Evidence, presented below in the discussion of the Phase C event, suggests that Phase B is pre-Late Wisconsin in age. Furthermore, it would appear that no major glacial event intervened between Phases A and B. Thus, Phase B is probably of either Illinoian or Early Wisconsin age.

d) Phase C Glaciation

The Phase C glaciation is the youngest glacial event to affect the western Cypress Hills region. Phase C sediments are exposed north of the Etzikom moraine and its extension south of Irvine and Walsh. This moraine therefore represents the maximum extent of the Phase C Glaciation. The Phase C tills are equivalent to the Etzikom and Oldman (Walsh) drift sheets recognized by Westgate (1964, 1972) and to the till north of the Etzikom moraine noted by Barendregt (1977).

Two distinct tills, formed during two separate stadials of Phase C, are present at Medicine Hat overlying a silt unit radiocarbon-dated at 24,490±200 BP (Dyck et al, 1965, p.8). Thus, Phase C is equivalent to the Late Wisconsin. The lower till is not seen on the surface anywhere in the study region, and is thought to represent an earlier, less extensive advance. The upper till is found on the surface everywhere north of the Etzikom moraine, and resembles the material which comprises that feature. The two tills are separated in the Medicine Hat area by lensose alluvial deposits which contain abundant faunal material (Stalker and Churcher, 1970). This assemblage suggests that some time must have elapsed between the

PLATE 5. Bedrock Exposures north of Comrey, locality CC-16e. Ice-thrusting of the bedrock has resulted in the formation of a series of ridges in this region. Note the absence of till cover.

PLATE 6, Phase C Till, Medicine Hat. The till is characterised by its marked tendency to form steep cliffs.

COLOURED PICTURE

deposition of the two tills.

Both these tills overlie either the Oldman Formation or other till material derived from it. Thus, the glacial sediments are composed largely of till derived from this formation. The most easily-recognizable characteristics of the exposed, uppermost Phase C drift are its silty texture (Figure 17), brownish-yellow colour (commonly 7.5 YR 6/5 m), and its strongly-developed columnar structure with pronounced vertical joints. The heavy mineral suite of the till resembles that of the Oldman Formation (Figure 18). There are few pebble-sized clasts in these sediments and virtually all are of Canadian Shield or Palaeozoic carbonate origin (Table 5).

Till exposed in bluffs along the South Saskatchewan River in the Medicine Hat area is correlated to the Phase C event on the basis of its stratigraphic position at the top of the pre-Holocene succession, its texture, and its columnar jointing pattern. Similar sediments are exposed along the Oldman River in the Bow Island area.

The strongly compacted nature and columnar jointing suggest that the till was subjected to considerable vertical load during and after deposition. This could be indicative of a basal till. The low void ratio, a characteristic of basal tills (Easterbrook, 1964), also suggests a subglacial origin (see Table 6).

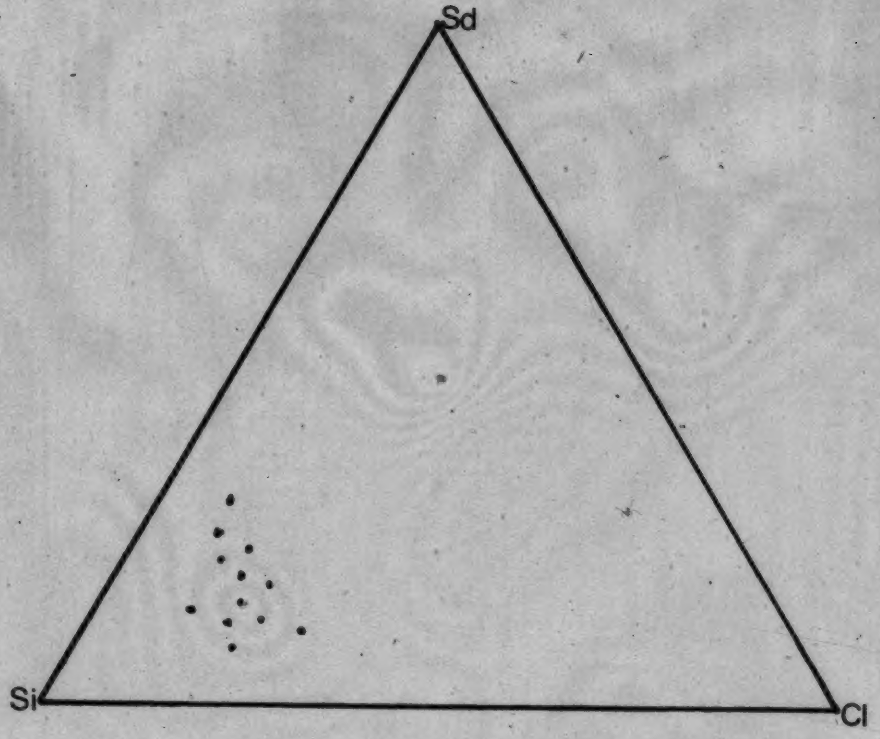


FIGURE 17 PHASE C TILL TEXTURES

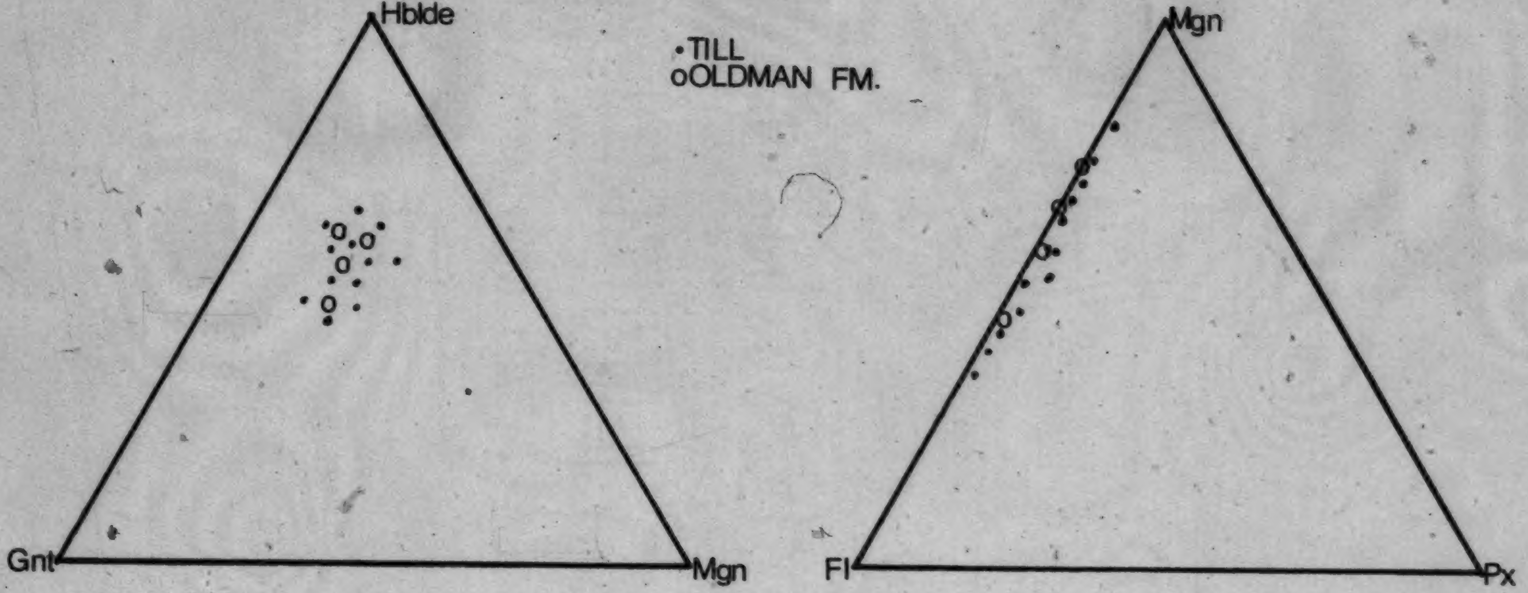


FIGURE 18 MINERALOGY, PHASE C TILL

Table 5

Pebble Composition of Phase C Basal Tills

Sample°	Canadian Shield Crystallines %	Palaeozoic Carbonates and Clastics %	Oldman %	Other Local %
IR-26	50	42	6	2*
IR-28	50	44	6	-
IR-29	48	48	3	1*
W-47b	45	40	10	5**
IR-57	39	48	7	6**
BH-120	47	44	4	5'
BH-121	52	47	1	-
SP-161	53	47	-	-
SP-162	55	44	-	1*
OR-168	52	46	-	2"

°Localities given in Appendix G.
* Foremost Formation
** Bearpaw Formation
' Foremost Formation, ironstone concretions and carbonate nodule, source indeterminate
" Foremost Formation and ironstone concretions, source indeterminate

Table 6

Void Ratios, Phase C Till

Sample	Void Ratio
IR-26	0.17
IR-29	0.21
IR-37b	0.20
W-47b	0.24
BH-120	0.16
BH-121	0.13
SP-161	0.14
OR-165b	0.15
OR-168	0.20

$$\text{Void Ratio} = \frac{\text{Porosity}}{1 - \text{porosity}}$$ (Easterbrook, 1964)

The porosity was determined by weighing a predetermined volume of till and assuming that the clasts had a specific gravity of 2.65.

Some ablation till associated with the Phase C advance is present as a thin, stony, unconsolidated cover over the basal facies. These units are lensose and discontinuous, except in the Walsh-Irvine area, where they form a thin cap averaging 0.5 m in thickness over the columnar-jointed unit. The units are equivalent to the Oldman till of Westgate (1964).

In this area, the relationship between the basal and ablation facies has been obscured by colluviation. Most of the sediment overlying the columnar-jointed basal till was formed by gravity-induced mass-wasting processes. The cutting of an intricate, intertwined system of meltwater channels during the final glacial recession produced many locations suitable for colluviation. The strongly-jointed basal facies is especially suitable to gravity-induced mass-wasting when it is exposed on channel-bank bluffs. The high proportion of montmorillonite in the till also contributed to its suspectibility to colluviation. Although the characteristics of ablation till and colluvium are often similar, the predominantly down-slope fabric pattern displayed (Figure 19) is typical of colluvium and is uncommon in ablation till (Marcussen, 1975). The presence of the material only along the slopes of meltwater channels of periglacial and postglacial origin also suggests that the sediment is non-glacigenic in nature. At some localities (eg. MI-268), the colluviated origin of of this sediment can definitely be established through the presence of

FIGURE 19.

MI-268 Fabric

The diagram illustrates the difference between the downslope orientation of MI-268 colluvium fabric and the random orientation of ablation till fabrics.

LEGEND

▤ ...... Area where 2% of clasts lie within counting circles

░ ...... Area where 5% of clasts lie within counting circles

■ ...... Area where 10% of clasts lie within counting circles

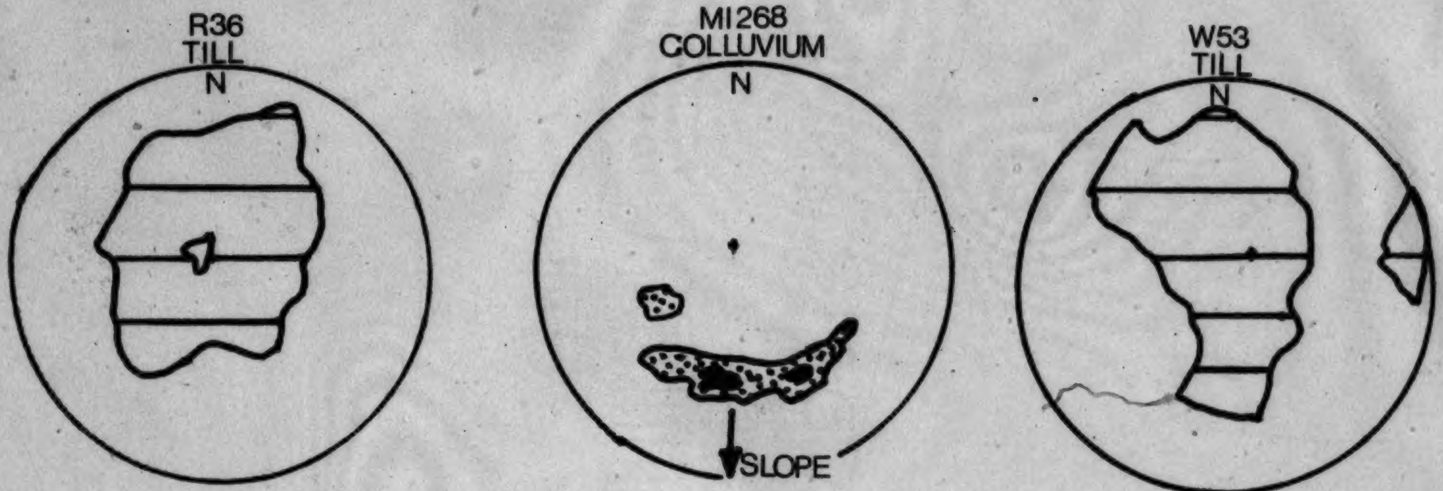

R36
TILL
N
MI 268
COLLUVIUM
N
SLOPE
W53
TILL
N

FIGURE 19 MI 268 FABRIC

bone fragments and remnants of non-periglacial vegetation. The lack of abrasion visible on the extremities of the bone splinters indicates that glacial transport of this material has not occurred.

Fabric analyses of the Phase C basal till indicate that the general direction of advance is southerly. The direction appears to shift gradually along the length of the moraine, from due south in the Walsh area to 150° azimuth in the vicinity of Nemiskam (Figure 20). No other large-scale geomorphic features or striations are present.

The age of the Phase C glaciation is considered to be Late Wisconsin, c. 17000 BP. The advance can be correlated with Phase 2 of Christiansen (1979), with the northernmost maximum Late Wisconsin position of Stalker (1977), and with position A of Stalker (1980, in preparation), on the basis of end moraine positions. Several arguments can be advanced which support Stalker's contention that this advance represents the Late Wisconsin maximum. Firstly, there is little doubt that the extent and continuity of the Etzikom-Lethbridge moraine indicate that it was formed by a major event. Secondly, the unaltered nature of the topography north of the moraine indicates that a significant difference in age exists between this area and that south of the moraine. Thirdly, the direction of ice advance agrees with that obtained from Late Wisconsin deposits in the Red Deer area (Stalker, 1960). Fourthly, the presence of surficial material in the Calgary area, radiocarbon-dated as older than Late Wisconsin (Jackson, 1979), indicates that this region lay beyond the Late Wisconsin glacial margin. Since

FIGURE 20.

Phase C Fabrics

The diagram illustrates the fabric pattern of Phase C basal tills.

LEGEND

E...... Elkwater
D...... Dunmore
I...... Irvine
M...... Manyberries
N...... Nemiskam
O...... Orion

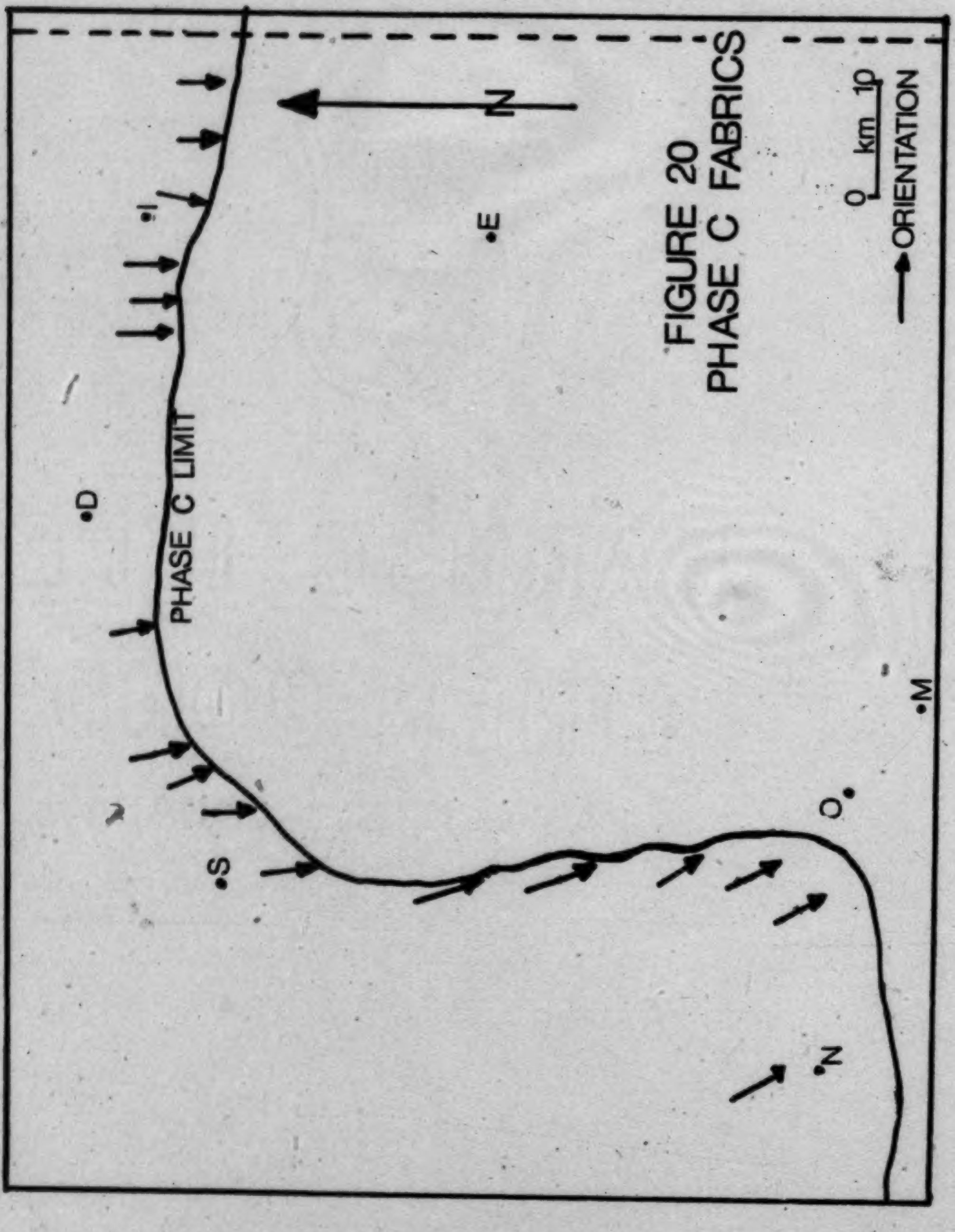

PHASE C LIMIT
D
I
E
N
S
O
M
N
0 km 10
ORIENTATION

FIGURE 20
PHASE C FABRICS

the closest moraine to the east is directly correlative to the Lethbridge moraine (Johnston and Wickenden, 1931), it seems evident that this moraine represents the maximum possible extent of Late Wisconsin ice. Since the Phase C maximum does represent the Late Wisconsin acme, it can be approximately dated at 20,000 - 18,000 BP.

A third Late Wisconsin advance to the north of the western Cypress Hills study region affected the Irvine-Walsh area by ponding meltwater from this area against its southern flank, hence disrupting the drainage system. The maximum ice front position is marked by the Fox Valley moraine, which extends east from the Schuler, Alberta area to Fox Valley, Saskatchewan. This advance correlates with Phase 3 of Christiansen (1979). The ice front position west of Schuler is unknown at present, as no till or moraine has yet been correlated to this advance.

GLACIOFLUVIAL DEPOSITS AND LANDFORMS

Glaciofluvial deposits and landforms are a relatively minor constituent of the Quaternary geology of the western Cypress Hills region. The deposits can be divided into two categories: outwash sands and gravels, including sandurs; and ice-contact deposits, including eskers and crevasse fillings. Meltwater channels and their deposits are discussed in the section dealing with fluvial features.

Outwash sands and gravels associated with early, pre-A glacial phases are found in several sections along the South Saskatchewan River to the north of the study area investigated by Stalker (1969a). Within the study region, the only pre-A glaciofluvial material exposed is the overridden sandur at location W-53, south of Walsh. Here, 6.1 m of interbedded clay, silt, sand, and gravel is overlain by a reddish-brown till representing a pre-A glaciation. Within the sandur sequence, truncated bedding, festoons and contorted laminations are common. The overall pattern of the sequence is progressive coarsening, suggesting that the glacier which was the source of the material was advancing toward the site. Individual fining-upward sequences reflect the channel switching commonly found in modern braided streams (Coleman, 1969).

The modal current direction, as recorded from sand and gravel clast orientations in the lower portion of the sequence, is approximately south-southeast. Divergence of flow by 45° from the modal current direction was recorded in some coarsening-upward sequences produced by gravel bar migration (Figure 21). This divergence is due to the diagonal currents produced by the bar itself(Hjulstrom, 1952). Divergence on either side of the modal direction by up to 60° has been recorded by Krigstrom (1962). The orientation of the current in the downglacier direction suggests that large-scale isostatic depression had not affected stream flow patterns in the region. Therefore, it can be inferred that this deposit was probably preliminary to a major glacial advance, and not a minor readvance or recessional stage. Topographic control in the region is insufficient to counteract even minor isostatic depression, and the absence of collapse structures and the general coarsening-upward sequence displayed do not support a supraglacial origin.

The presence of horizontal stratification led Westgate (1964) to conclude that the lower portion of this unit was lacustrine in origin. However, the cross-laminated units associated with the laminarly-bedded sands indicate that both sediments were deposited under conditions of unidirectional flow to the south-southeast. Since this flow direction parallels that measured in the gravel bar sequences, it would appear likely that both sequences were produced in the same environment. Similar associations have been noted in modern stream deposits (Allen, 1964), as well as in the periglacial environment (Shaw, 1972). Contortions were observed to increase with

FIGURE 21.

Sandur Sequence, Locality W-53

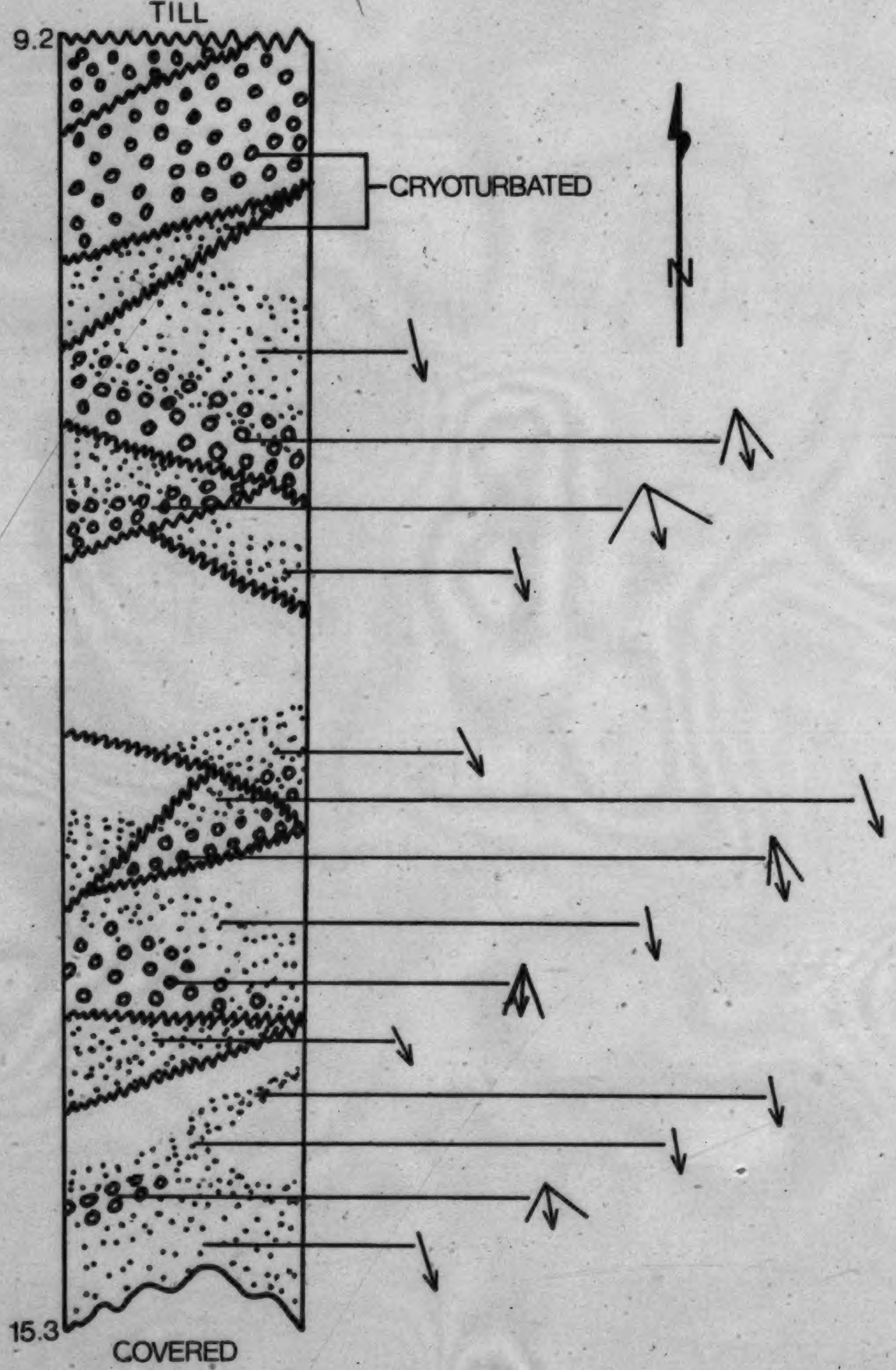
The diagram indicates the nature of the sandur sequence exposed at locality W-53, and the current direction measurements obtained throughout the section. The sequence is overlain by 9.2 m of other sediments.

LEGEND

○ Gravel
⁘ Sand
☐ Silt

→ Modal Current Direction
< Range of Measured Current Directions
〰 Unconformable Contact
9 Depth Below Ground Surface (m)

Vertical Scale: 1 cm = 30 cm


TILL
9.2
CRYOTURBATED
N
15.3
COVERED

elevation in the deposit, but it could not be discerned whether these were produced by frost action or by glaciotectonic disturbance. Probably, a combination of both processes was operative.

Similar, though less thick, sequences are preserved beneath deposits of both the Phase A (i.e. IR-30, IR-31) and Phase B (i.e. R-24, W-53) glaciations. Characteristically these deposits are predominantly gravel, with lesser proportions of sand and relatively little silt and clay. Palaeocurrent directions vary, but most tend to be at right angles to the direction of glacial advance as recorded in the overlying till (Figure 22a). All have an easterly component of flow, in keeping with the present regional flow pattern, and the assumed preglacial drainage network as revealed by buried channels excavated in the bedrock (Farvolden, 1963). The deposits can easily be differentiated from preglacial gravels due to the presence of Canadian Shield-origin granitic, gneissic, basaltic, and Palaeozoic carbonate clasts.

Little outwash gravel associated with the Phase C glaciation was discovered, as was indicated by the work of Westgate (1964). Phase C tills almost always directly overlie material deposited during the Phase B glaciation. This absence of fringing outwash material may be due to the mode in which the Phase C glacier advanced into the region. After reaching the initial, more northerly position at the beginning of the Late Wisconsin (represented by the lower Late Wisconsin till noted at Medicine Hat by

FIGURE 22.

Paleocurrent Directions, Phase B Glaciofluvial Sediments.

Figure 22a illustrates the paleocurrent directions in the two glaciofluvial gravel deposits underlying Phase B till. The modal current directions are at right angles to the directions of glacial advance.

Fibure 22b illustrates the paleocurrent directions in two esker deposits associated with the Phase B glaciation. The modal current directions are southeasterly, corresponding to the directions of glacial advance.

Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

⟶ Direction of glacial advance.
Scale: 2.6 cm = 10 clast measurements.

FIGURE 22a

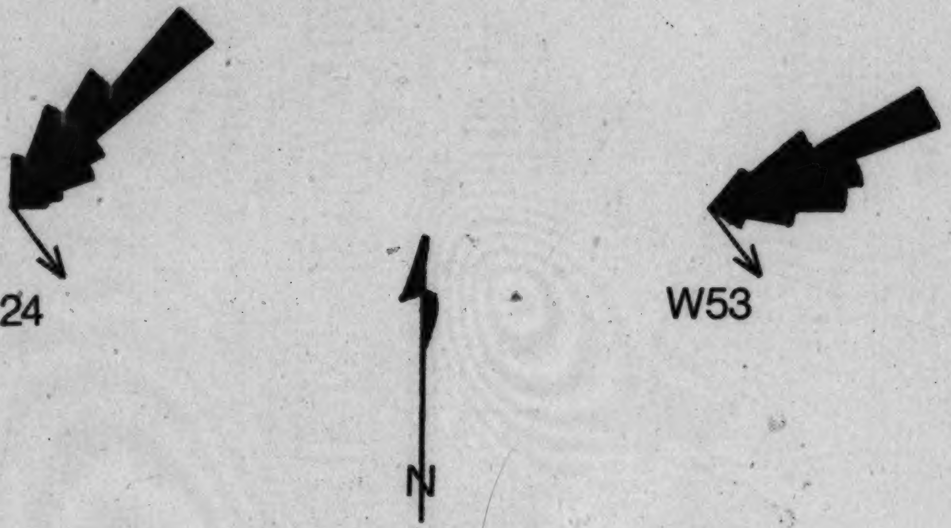
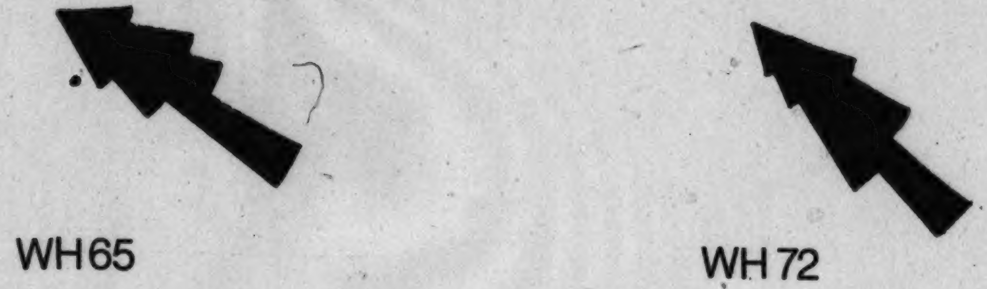


FIGURE 22b



Stalker (1969a)), the glacier retreated far enough to allow the interstadial fauna at Medicine Hat (Stalker and Churcher, 1970) to develop. Subsequently, the glacier readvanced to the position marked by the Etzikom moraine. The scarcity of outwash plain deposits in comparison with the amount produced during the Phase B event can be explained it is assumed that the Phase C readvance was rapid, an assumption which is supported by the uniformity of its direction of advance as measured in the study area. The pattern of isostatic depression and subsequent recovery, as recorded by lake levels, also suggests a rapidly-moving advance (see Isostatic Recovery section). When the glacier retreated, it withdrew relatively rapidly also, as indicated by the stratigraphy and radiocarbon dates obtained from Saskatchewan (Christiansen, 1979), and central Alberta (Westgate, 1969). This relatively rapid withdrawal, combined with pre-withdrawal ablation, limited the production of proglacial outwash plains.

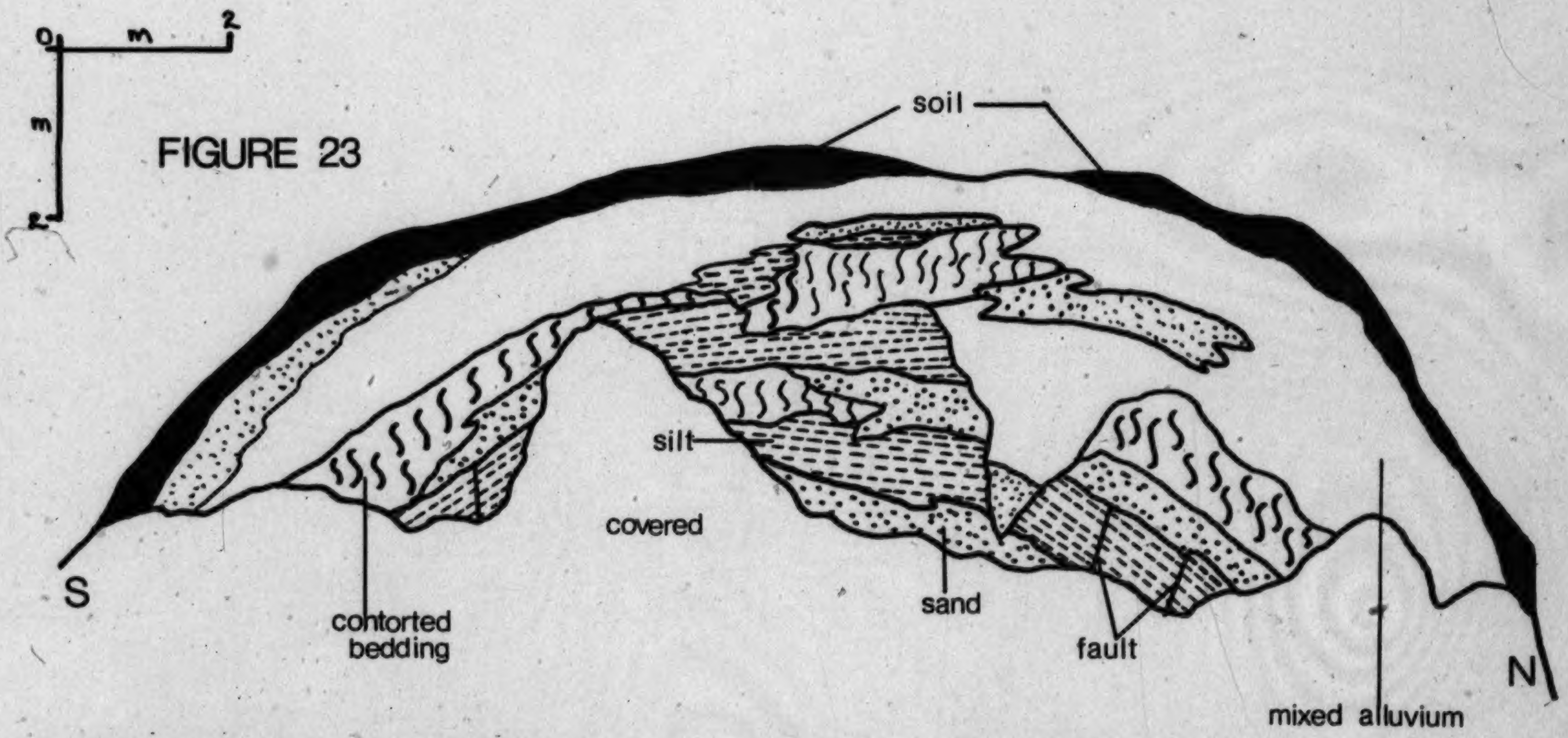
Ice-contact deposits associated with the Phase B retreat are found in the Wild Horse-Bain area (Westgate, 1964). These include both crevasse fillings and southeast-northwest trending eskers. Commonly, these features grade laterally into each other. Both landform types were produced in the same environment: the predominantly vertically-ablating Phase B glacier during the retreat from the maximum position. Both predate the development of Lake Wild Horse, and features in the lake basin have been scoured and altered by the lacustrine event.

The eskers commonly display arcuate cross-sections, and are characterised by interbedded sand and gravel lenses and layers concentric about the base of the feature (Figure 23). Both fining-upward and coarsening-upward sequences are common, and often can be found alternating vertically within the same esker. Commonly, the sandy units display heavy-mineral cross-stratification, and the gravels are usually imbricated. Both indicate that the dominant current direction in all cases was to the southeast (Figure 22b). This direction, towards the edges of the glacier, would be expected in a structure whose development was controlled by glacier morphology.

The crevasse fillings are less well-defined than the eskers, and are less continuous. They also display arcuate cross-sections, but their internal structure is not preserved. Instead of a series of concentric rings, the interior of a crevasse filling reveals a structureless jumble of sand and gravel. Silt is also present in sizable amounts in contrast to the sand-dominated eskers. The crevasse fillings bifurcate and join in a highly irregular manner, and often meet at angles in excess of 60°.

The environments of formation of these two features have been linked by several investigators (e.g. Price, 1966; Shaw, 1972). The arcuate nature of both features indicates that they were supported by ice at the time of their formation, and that withdrawal of that support caused the sides to collapse, while the centre remained high. Disagreement has centred around the question of the exact environment

FIGURE 23


0
m
2
m
2
soil
silt
covered
contorted bedding
sand
fault
mixed alluvium
S
N

CROSS-SECTION THROUGH SAGE CREEK ESKER, LOCATION WH65

PLATE 7. Normally-faulted Glaciofluvial (esker) sand, Locality WH-65. The normal faulting results from collapse of the sediment upon removal of the ice supporting the sub- or supraglacial tunnel or channel.

PLATE 8a. Climbing Ripple Lamination, Sage Creek Esker, Locality WH-65. This sedimentary structure indicates relatively low energy level flow.

COLOURED PICTURE

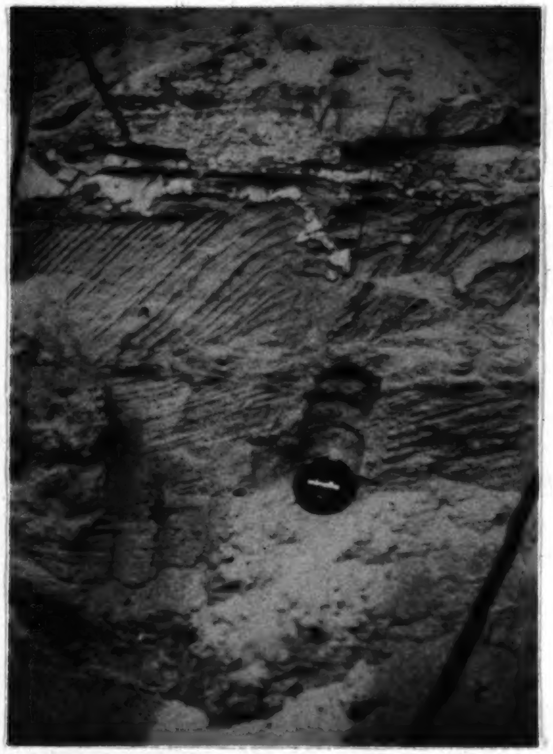


PLATE 8b. Moderate Angle Cross-Bedding, Sage Creek Esker, Locality WH-65. This sedimentary structure indicates a moderate rate of glaciofluvial water flow.

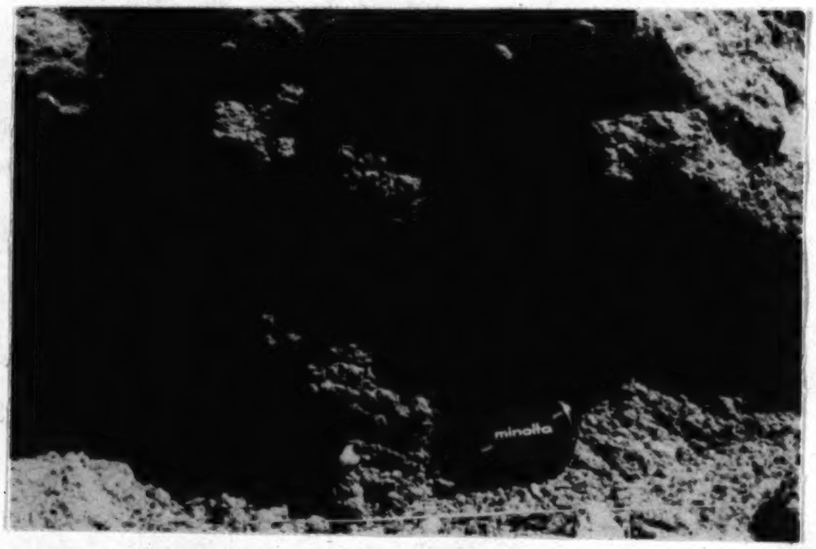


PLATE 8c. High Energy Gravel Facies, Sage Creek Esker. Vertical and lateral changes in flow regime are characteristic of most eskers and glaciofluvial deposits.

COLOURED PICTURE

of deposition of the eskers. Some investigators (eg. Radlowska, 1969; Phillipp, 1912), feel that the ridges were formed in sub- or englacial tunnels, while others (eg. Price, 1966) believe that a supraglacial origin explains their occurrence more satisfactorily.

In the study area, features suggesting formation by both processes were noted. The gradation of eskers into crevasse fillings, which are unquestionably of supraglacial origin, implies that these landforms are supraglacial. This conclusion is also supported by the fact that the current direction closely mirrors the regional slope of the former ice surface. However, the systematic decrease in elevation along the flow direction of several eskers indicates that topographic inversion of these features has not occurred. Such inversion would occur had these landforms originated on the surface of an ablating glacier. The absence of associated supraglacial produced features, such as kames, also indicates that supraglacial activity was limited during the formation of some eskers. Finally, the eskers display an unusual dependence on topography. The development of eskers along bedrock valleys would be more likely if the eskers formed subglacially, not supraglacially. It appears, therefore, that the area's eskers have formed in both the sub- and supraglacial environments.

LACUSTRINE DEPOSITS AND LANDFORMS

Lacustrine events and sediments represent the major means of correlating and dating glacial advances in the Western Cypress Hills region due to both their stratigraphic position and the effects of isostatic recovery. In the following paragraphs, the characteristics, extents, and palaeoclimatic implications of these lacustrine sequences will be discussed.

In the study region, five major lacustrine sequences can be recognized: Lake Wild Horse (Westgate, 1964), in the vicinity of Wild Horse; Lake Gros Ventre, on the western flank of the Cypress Hills Plateau; a series of lakes formed in the Pakowki basin after the glacial retreat from the Phase B maximum position; a second series of Pakowki lakes formed during and after the Phase C withdrawl; and a lake in the Many Islands basin. All of these lakes fluctuated in response to climatic changes, and their flora and fauna serve as indicators of palaeoclimates, not only in the lake waters but in the terrestrial environments as well. In addition, many minor supraglacial lakes were formed at various times during the retreats of the Phase B and C glaciers.

In order to be classified as lacustrine beach sediment, a deposit must possess the following characteristics:

1) A coarse-medium grained sand texture,
2) A topographic position approximately parallel to the local contours and incompatible with fluvial deposition,

3) Either laminar bedding or low-angle (8-10°) cross-bedding.

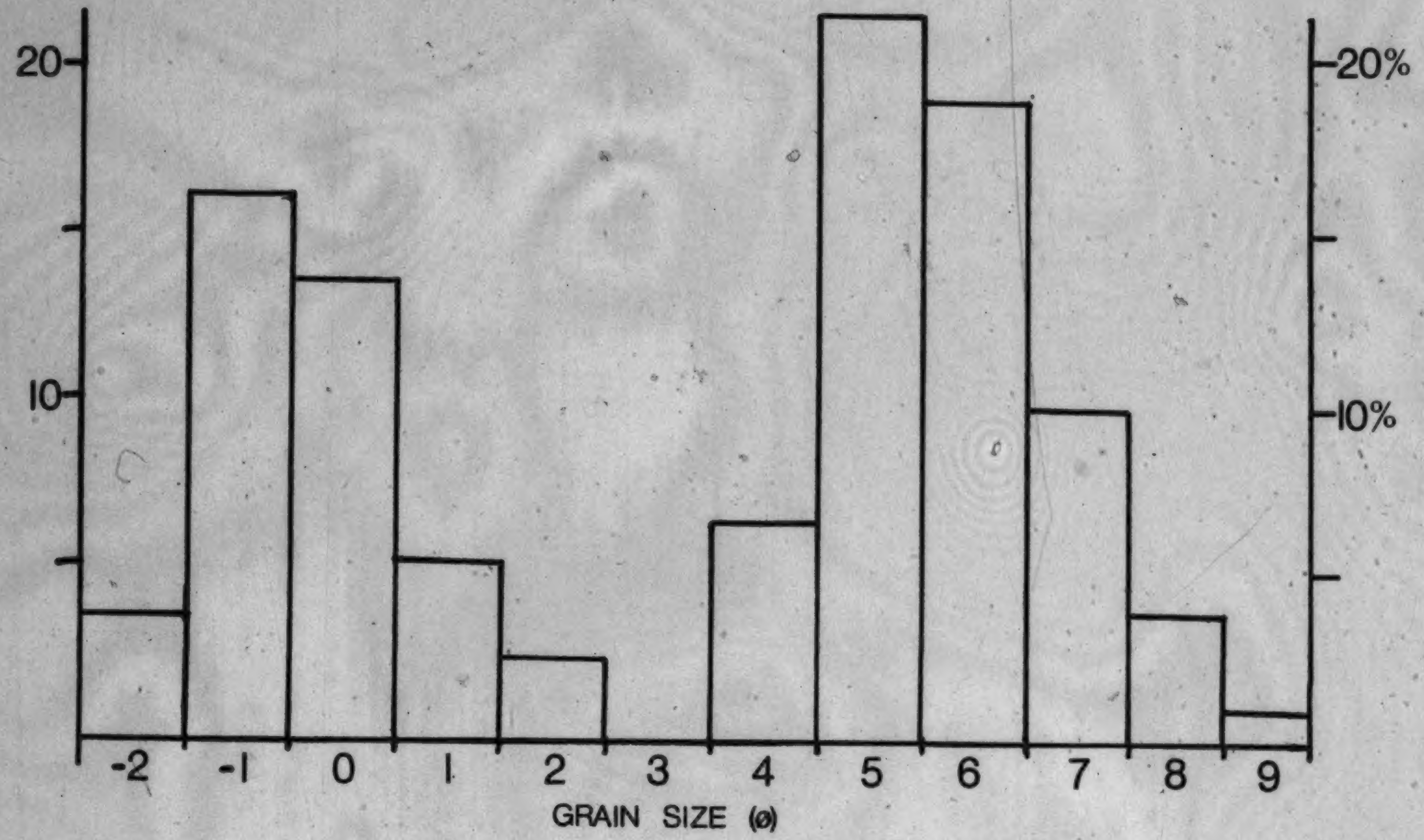
Additional evidence for lake limit positions is provided by the presence of wave-washed sediments. These deposits can be distinguished from unaltered sediments of the same original genetic type by their coarser texture relative to the unmodified sediment, the reorientation of clasts by wave action evident in the altered material, and the topographic position of the washed zone nearly parallel to the contours. In some instances, the removal of finer-grained matrix material from a grain-supported sediment results in an "open-work" structure. This is especially common in coarse-grained sediments, such as glaciofluvial gravels. Exposure to the air and other flowing water inevitably results in the disaggregation of these sedimentary structures, so that their preservation in unaltered form is relatively uncommon. In some instances, the open-work structure may be infilled by materials deposited at a later time (eg. loess). The strongly bimodal textural composition of such sediments enables their dual provenance to be readily recognized (Figure 24).

Downcut deltas are another indicator of former lake levels. A decrease in the water level causes the former deltas of tributary streams to be above the new lacustrine limit. As these tributary streams adjust their gradient in order to reach the new base level, they erode channels (downcut) the former delta. Since the presence of a delta indicates a standing body of water, the elevation of a former

FIGURE 24.

Open-Worked Gravel Textural Composition, Locality WH-69b.

The Figure illustrates the textural composition of an open-worked gravel deposit, subsequently infilled with loess. The bimodal nature of the sediment is strongly apparent from the histogram. The modal size of the gravel particles is 0.5 Ø; the loess modal size is 5.5 Ø.


20
10
-20%
-10%
-2
-1
0
1
2
3
4
5
6
7
8
9
GRAIN SIZE (ø)

water surface can be inferred from the position of abandoned deltaic sediments.

a) Lake Wild Horse

Glacial Lake Wild Horse was formed in the southeastern corner of the Western Cypress Hills region, and overlies sediments deposited during the retreat of the Phase B glacier. Some of these sediments have been modified by the lacustrine event. The uppermost lacustrine sediments are dominantly sandy, with a systematic increase in silt content towards the southern extremity of the basin (Figure 25). This sedimentary pattern indicates that Lake Wild Horse gradually shifted to the southeast, causing coarser-grained sediments to be deposited atop fine-grained material in the northerly areas of the lake's extent. Although most of the sediments are apparently structureless, careful examination reveals that coarsening-upward graded bedding sequences are present in most exposures of lacustrine sediments (eg. WH-67, WH-68). Imbrication of the sand clasts suggests that the predominant direction of water flow in the lake was toward the southeast (Figure 26). The generally sandy nature of the sediments and the similarity of current directions throughout the basin indicate that the water occupying the area remained relatively shallow throughout its existence. The absence of strongly-developed shorelines also suggests that the lake was small and short-lived.

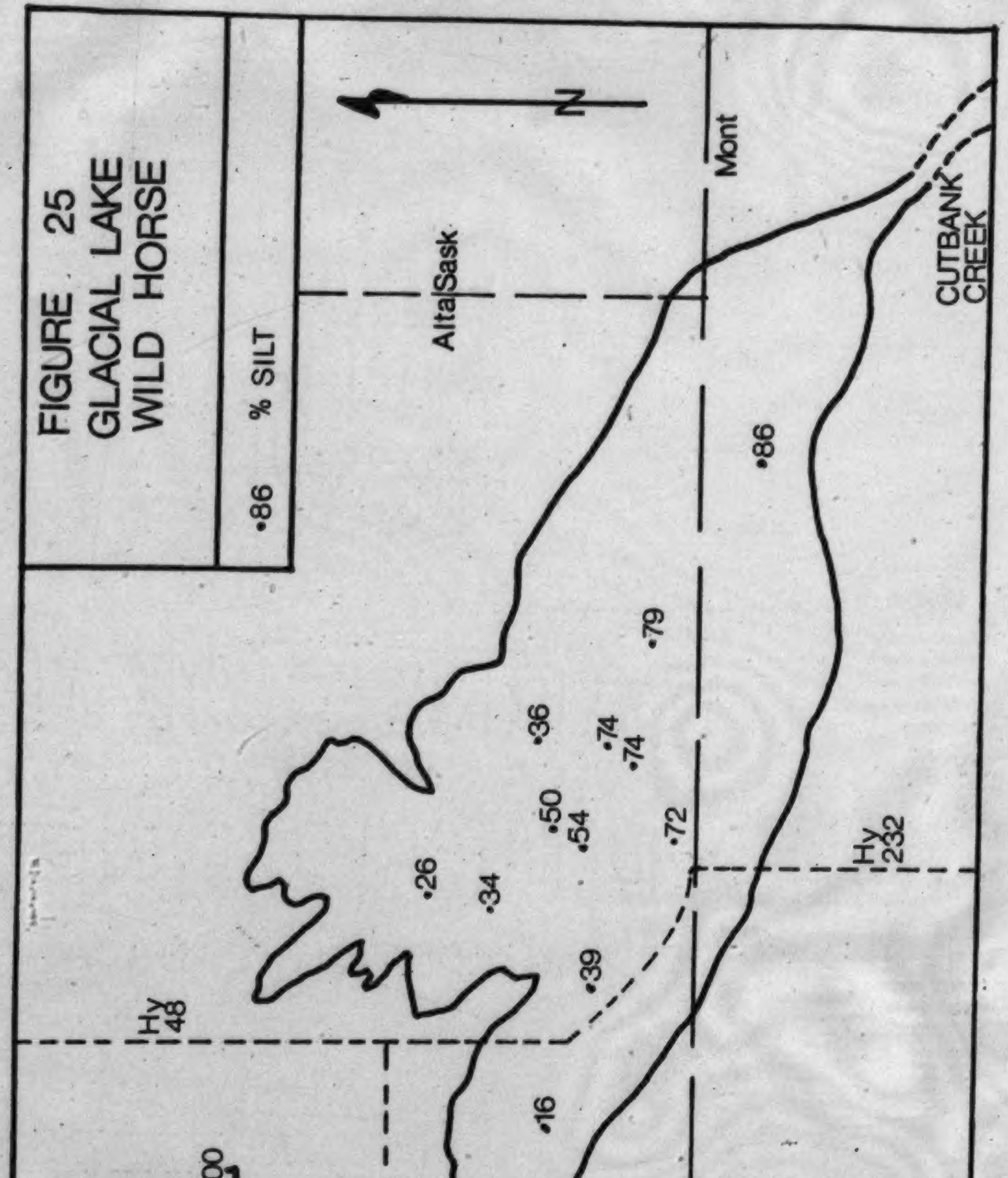


FIGURE 25
GLACIAL LAKE
WILD HORSE

•86
% SILT
N
Alta|Sask
Mont
CUTBANK CREEK
Hy 232
Hy 48
Hy 501
0
m
500
•86
•79
•36
•74
•74
•50
•54
•72
•26
•34
•39
•16

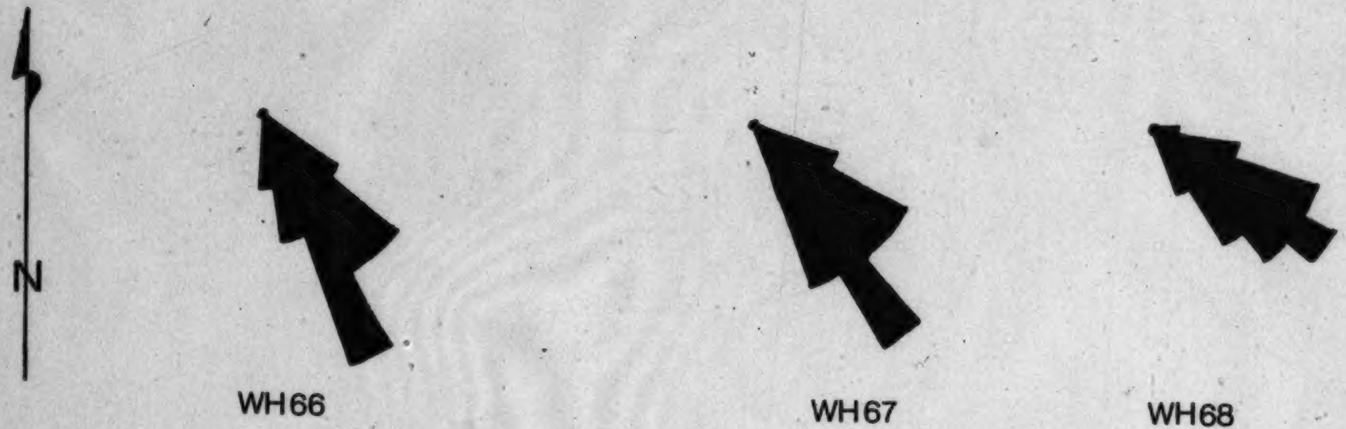
FIGURE 26.

Paleocurrent Directions, Lake Wild Horse Sediments.

The figure illustrates the paleocurrent directions at three localities from the central area of Lake Wild Horse. The modal current directions are southeasterly. Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale: 2.6 cm - 10 clast measurements

FIGURE 26



Three distinct stages of Lake Wild Horse marked by lacustrine sediments and distinctive diatom assemblages successively occupied the basin area (Figure 27 and Table 7). Immediately following deglaciation, lake waters attained a maximum elevation of 890 m along the northern flank of the basin. Correlation of the elevations of the highest lacustrine beach sediments, downcut deltas of tributary streams, and wave-washed till and glaciofluvial gravels (Table 8) reveals that the lake shoreline level decreases systematically towards the southeast, to a minimum of 840 m. The direction of maximum change in shoreline elevation is perpendicular to the ice front as inferred from the position of the Phase B moraines in the study area and correlated moraines in northern Montana (Westgate, 1964). The position of this shoreline, as inferred from both field observations and interpretation of aerial photographs by the author, corresponds with the Lake Wild Horse border of Westgate (1964). This lake phase, which drained to the southeast _via_ Cutbank Creek, is designated as Lake Wild Horse I.

Examination of the diatom flora present in the lake sediment revealed that the assemblage is dominated by _Tabellaria sp_. and _Asterionella sp_. This assemblage is typical of cold, oligotrophic lacustrine conditions (Rawson, 1956; Bradbury, 1974). The harsh periglacial climate limited the amount of organic material present and delayed its decomposition, enabling the lake to remain oligotrophic in nature despite its limited depth.

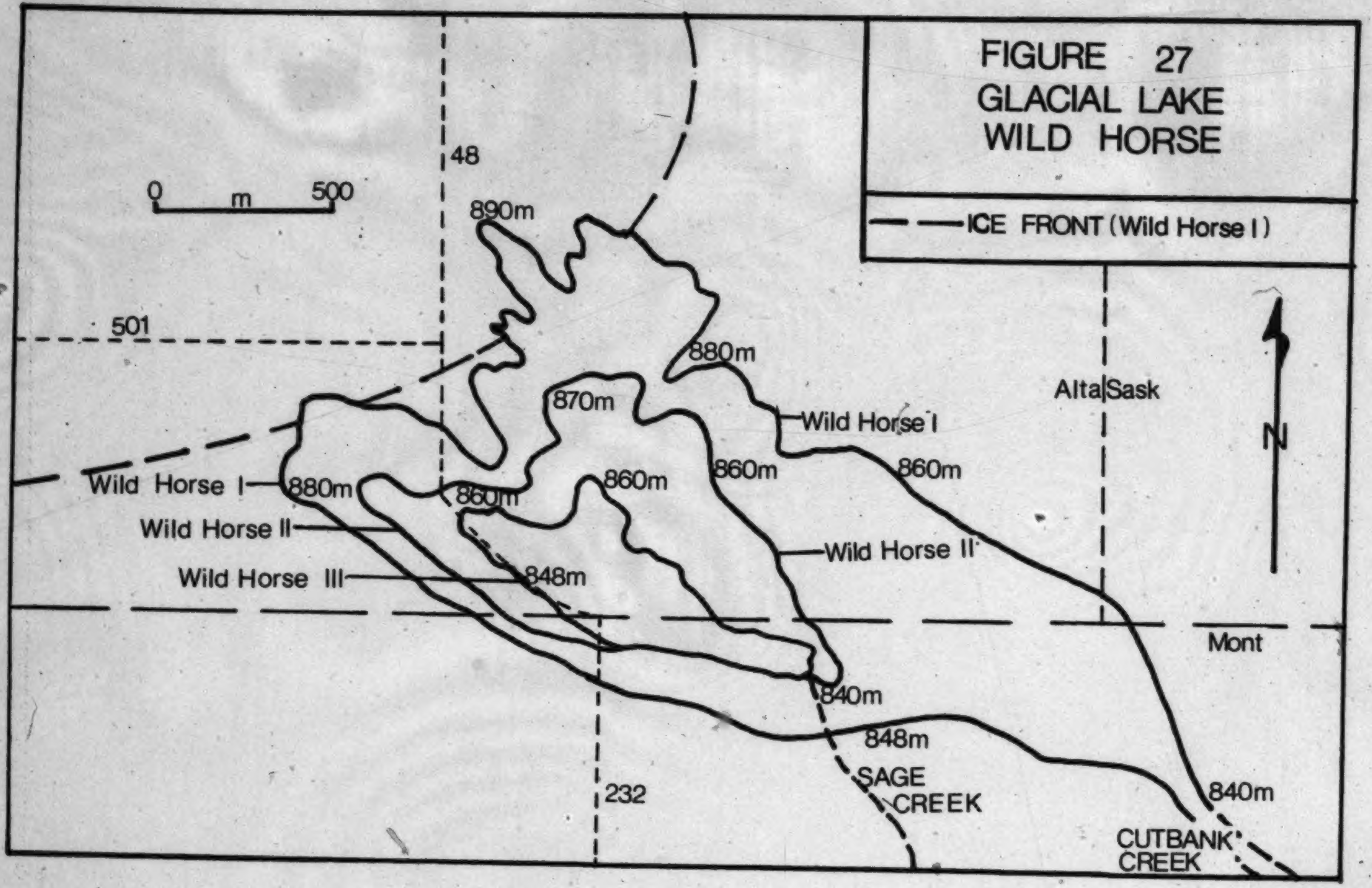


FIGURE 27
GLACIAL LAKE
WILD HORSE

ICE FRONT (Wild Horse I)
0 m 500
48
501
232
890m
880m
870m
860m
860m
860m
860m
880m
848m
840m
848m
840m
Wild Horse I
Wild Horse II
Wild Horse I
Wild Horse II
Wild Horse III
Alta Sask
Mont
N
SAGE CREEK
CUTBANK CREEK

TABLE 7

Stages of Glacial Lake Wild Horse

Name	Maximum Elevation	Outlet and Elevation	Diatom Assemblage
Wild Horse I	890 m	Cutbank Creek 840 m	*Tabellaria-* *Asterionella*
Wild Horse II	870 m	Sage Creek 840 m	*Cerateum-* *Stephanodiscus*
Wild Horse III	860 m	Sage Creek 840 m	*Eutonia-* *Melosira distans*

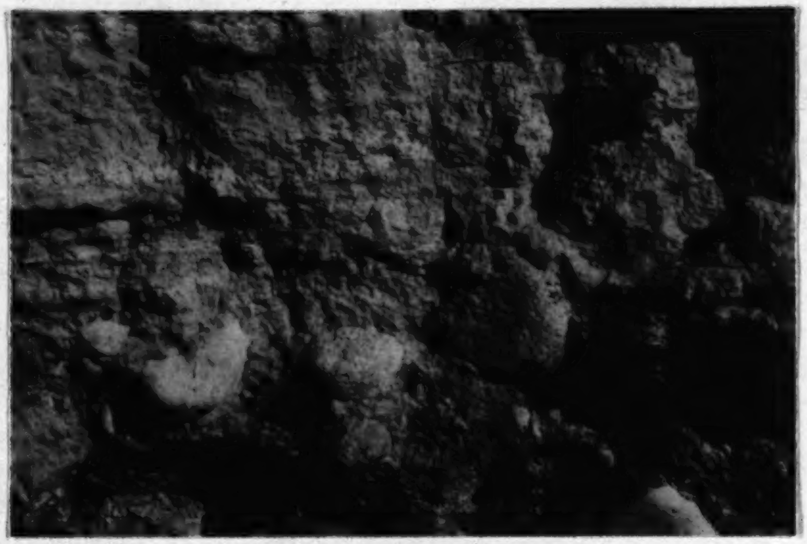


PLATE 9. Wild Horse I sediments overlying Glaciofluvial Gravel, Locality WH-66. The lacustrine sediments are predominantly silt. Although varving is present at this locality, it is highly discontinuous in nature and of no value for correlative purposes.

COLOURED PICTURE

TABLE 8

Limits of Lake Wild Horse I

Locality*	Elevation	Distance/Bearing from Outlet**	Feature
WH-233a	890 m	2700 m/ 309	Beach Sediments
WH-233e	885	2400 / 313	"
WH-234b	880	2500 / 294	Wave-washed gravel
WH-69d	880	2300 / 322	Downcut Delta
WH-69c	878	2100 / 319	Beach Sediments
WH-69b	870	1700 / 314	Wave-washed gravel
WH234c	870	2400 / 288	Wave-washed till
WH-69a	865	2200 / 312	Beach Sediments
WH-235e	860	1300 / 314	"
WH-235f	858	1000 / 320	"
WH-235g	855	900 / 326	Downcut Delta
WH-235h	852	650 / 335	Beach Sediments
Montana Rte. 232	854	1700 / 281	Wave-washed till
Sage Creek (East Bank)	848	1050 / 280	Beach Sediments
Cutbank Creek	840	-------------	"

*Localities given in Appendix G
**Distances and azimuth bearings measured from intersections of Cutbank Creek and southernmost lacustrine beach sediments.

The only other fossils found in Lake Wild Horse I sediments were the ostracods Limnocythere staplini, Candona obtusa, C. rostrata, and Cypris pubera. These ostracods are characteristic of cold, oligotrophic lakes (Delorme, 1970-71), an environment conforming with that inferred from the diatom assemblage.

The existence of this lake, and the absence of any confining feature or evidence for the presence of stagnant ice southeast of the lake, suggest that the Wild Horse basin may have been initially formed by isostatic depression due to glacial loading. This mechanism also explains the discrepancy between the elevation of the northernmost sediments of the lake (890 m), and the position of the outlet, 50 m lower. Theoretical considerations, discussed in the section dealing with isostatic recovery, indicate that a total depression of 50 m lies well within the limits expected upon the disintegration of the Phase B ice sheet.

A second lacustrine limit can be delineated from a lower series of 8-10^0 cross-bedded sand units and wave-washed glaciofluvial materials (Table 9). The elevation recorded along the northern flank, 870 m (WH-233b), as indicated by cross-bedded lacustrine beach sediments, marks the maximum height achieved by the lake waters of this second phase. The minimum elevation of 840 m was recorded at the point where Sage Creek intersects the lacustrine limit. Presumably, therefore, this stream served as the outlet for this lacustrine phase, here designated Wild Horse II.

TABLE 9

Limits of Lake Wild Horse II

Locality*	Elevation	Distance/Bearing from Outlet **	Feature
WH-233b	870 m	1300 m/ 324	Beach Sediments
WH-233h	866	1050 / 318	"
WH-234a	865	1400 / 293	Wave-washed till
WH-235b	860	850 / 327	"
WH-233i	860	1000 / 308	Wave-washed gravels
WH-233j	857	950 / 305	Wave-washed silts
WH-234d	855	1250 / 289	Beach Sediments
WH-235c	854	750 / 335	"
WH-234e	852	900 / 282	Wave-washed till
WH-235d	850	400 / 343	Beach Sediments
Montana Rte. 232	844	600 / 278	Wave-washed silts
Sage Creek	840	-----------	Beach Sediments

*Localities given in Appendix G
**Distances and azimuth bearings measured from intersection of Sage Creek and southernmost lacustrine sediments of Lake Wild Horse II

This progressive shallowing, combined with climatic amelioration following deglaciation, produced a different diatom-ostracod assemblage. The diatoms were dominated by Cerateum sp and Stephanodiscus sp, indicative of mestrophic conditions. Similar conditions are indicated by the presence of Potamocypris smaragdina and Cypridopsis vidua (Delorme, 1970-71). Specimens of Vertigo modesta and Succinea avara were also found in nearshore lake sediments. These gastropods were transported to the lake by inflowing streams, as indicated by the orientation of the associated feldspar clasts (Figure 28). The presence of these terrestrial gastropod species could indicate that the vegetation surrounding the lake was boreal to sub-boreal in nature, developed under the influence of a cold temperate climate.

The decline in the water levels from north to south indicated by the lacustrine limit suggests that isostatic recovery of the area was continuing at the time of the lake's formation. Isostatic recovery in the eastern area of the basin isolated the former Cutbank Creek outlet from this lake, causing it to drain through the more westerly Sage Creek.

The lowest lacustrine limit in the Wild Horse area is marked by fragmentary evidence consisting of bands of medium-coarse grained lacustrine sand (Table 10). Recognition of these sediments is hindered by the presence of loess overlying much of the area, and the flooding caused by the construction of the Milk River Reservoir. The highest

FIGURE 28.

Paleocurrent Directions, Lake Wild Horse II Shorelines.

The Figure illustrates the paleocurrent directions at three localities along the Lake Wild Horse II shoreline. The paleocurrent direction is southeast in all cases. Gastropods were found at each locality, but the numbers were insufficient for dating purposes. Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale: 2.6 cm = 10 clast measurements.

FIGURE 28

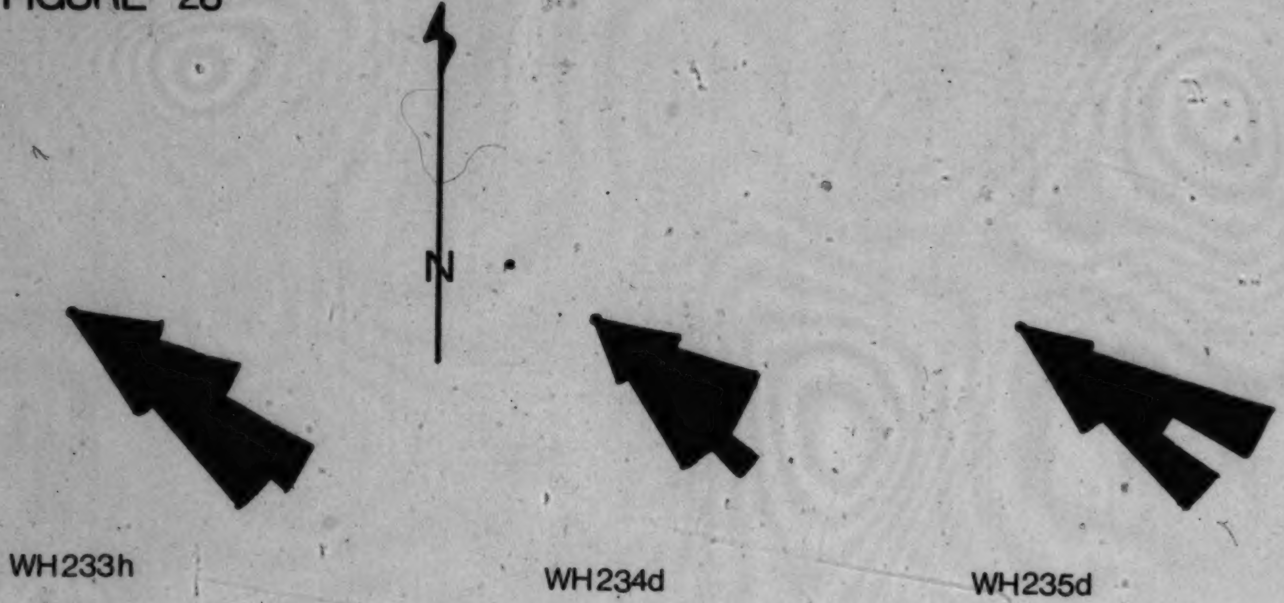

N
WH233h
WH234d
WH235d

TABLE 10

Limits of Lake Wild Horse III

Locality*	Elevation	Distance/bearing from outlet**	Feature
WH-233c	860 m	800 m/ 310	Beach Sediments
WH-233d	858	1000 / 294	"
WH-67	855	750 / 300	"
WH-235a	852	600 / 308	"
WH-233g	848	450 / 288	"
Sage Creek	840	-----------	"

*Localities given in Appendix G

**Distance and azimuth bearings measured from intersection of Sage Creek and northernmost lacustrine beach sediments of Lake Wild Horse III within Montana.

elevation, 860 m, was recorded at locality WH-235c, along the northern flank of the lake. The minimum elevation was 840 m, along Sage Creek in Montana. This phase, designated Lake Wild Horse III, was a very shallow lake. The water depth over almost all of its area was less than 5 m. Drainage was to the southeast, through Sage Creek.

The shallowness of the lake is reflected in the diatom assemblage, and in the amount of material added from the surrounding terrestrial environment. Eunotia sp. and Melosira distans are the dominant forms, suggesting a slightly acidic, very shallow lake (Brugham, 1980). The acidity of the lacustrine environment may have been a result of the establishment of a pine forest around the lake, subsequent to the retreat of the Phase B glacier, creating conditions similar to those observed in Minnesota by Brugham (1980). An additional indication of fringing pine-dominated vegetation is provided by the transported terrestrial gastropod assemblage. Vertigo modesta, Discus cronkhitei, Oreohelix sp, Zonitoides sp, and Retinella sp are all present, and similar assemblages have been observed to be currently present in the forested northern escarpment area of the Cypress Hills Plateau (Russell, 1951). The postulate of a pine forest would require the climate of the area surrounding the lake to be somewhat moister than at present.

Thus, the Wild Horse series of lakes developed under changing

TABLE 11

Summary of Environmental Characteristics, Lake Wild Horse Stages

Stage	Diatom Assemblage	Environmental Classification*
Lake Wild Horse I	*Tabellaria- Asterionella*	Cold, Oligotrophic
Lake Wild Horse II	*Cerateum- Stephanodiscus*	Cool, Mesotrophic
Lake Wild Horse III	*Eutonia- Melosira distans*	Cool, Eutrophic (slightly acidic)

*Based upon the criteria of Rawson (1956), Bradbury (1974).

conditions caused by climatic amelioration and isostatic recovery. The absence of well-developed shorelines indicates that the transition between the lake stages and the total period of lacustrine coverage of the area occupied a relatively short time. Since isostatic recovery progresses very rapidly immediately following deglaciation, the temporal existence of a lake dependent upon glacioisostatic depression would be expected to be limited.

b) Lake Gros Ventre

The ice front position of the Phase B maximum in the plateau escarpment area created a confined basin in the headwater areas of Gros Ventre Creek and Medicine Lodge coulee. Consequently, a linear pond formed in the coulee, reaching a maximum elevation of approximately 1270 m during the Phase B retreat. This water body is here termed Lake Gros Ventre (Figure 29). No strandlines or other indications of level were found, save for the positions of sandy lacustrine beach sediments (Table 12).

Differential elevations recorded among the lacustrine sediments indicate that the former water surface was warped due to glacioisostatic effects. However, because the lake was bordered by ice on three sides, the differential progress of isostatic recovery of each sector of the ice sheet altered the positions of the individual exposures of lacustrine sediment relative to each other, making analysis of lake levels difficult. No palaeontological elements were present in any of the lacustrine sands or silts observed.

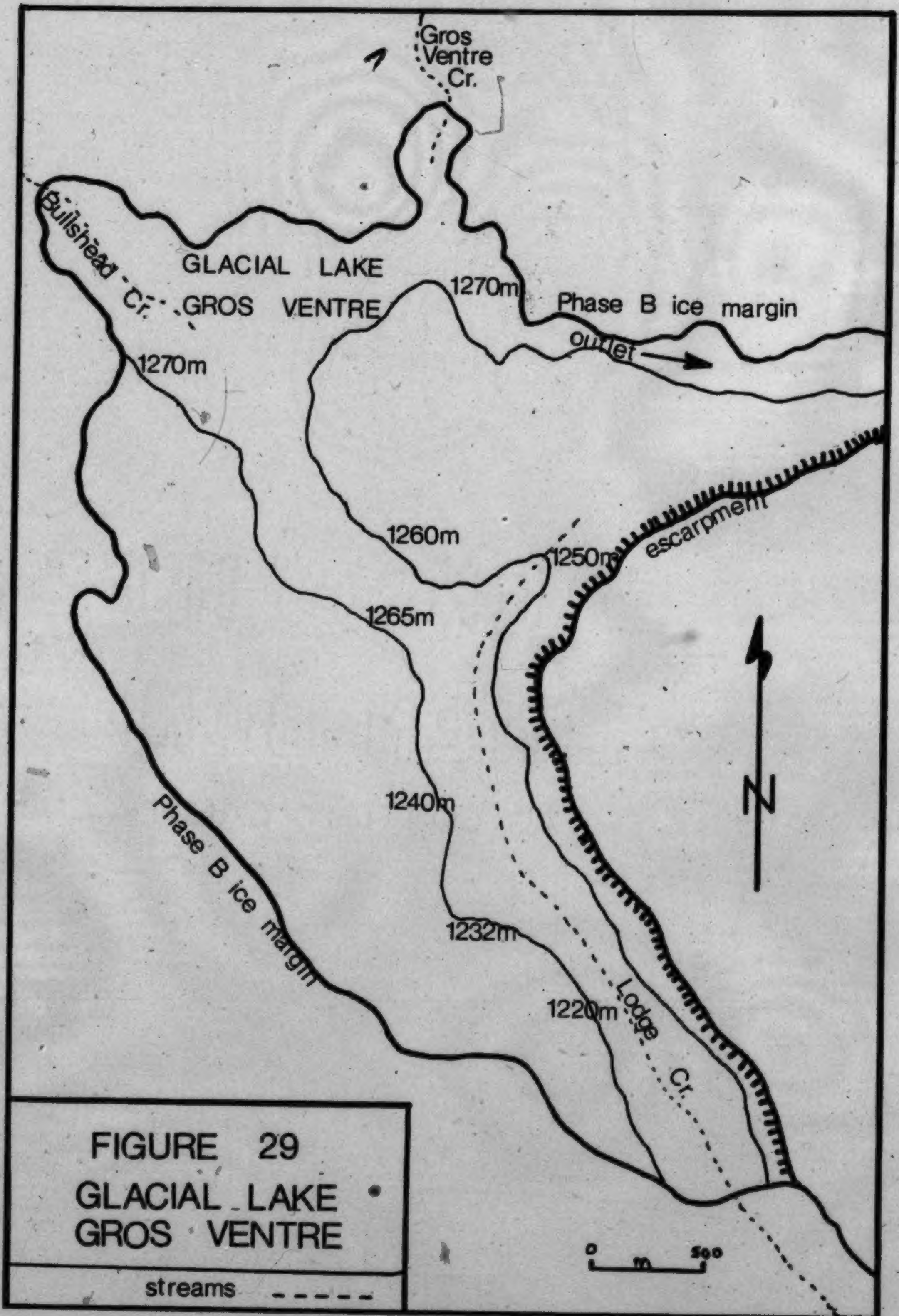

Gros
Ventre
Cr.
Bullshead Cr.
GLACIAL LAKE
GROS VENTRE
1270m
Phase B ice margin
outlet
1270m
1260m
1250m
escarpment
1265m
1240m
Phase B ice margin
1232m
1220m
Lodge Cr.
N
0 m 500
streams -----

FIGURE 29
GLACIAL LAKE
GROS VENTRE

TABLE 12

Limits of Lake Gros Ventre

Locality*	Elevation	Feature
E-34	1270 m	Beach Sediments
ML-141h	1270 m	"
ML-141g	1265 m	"
ML-141f	1260 m	"
PL-103g	1250 m	"
ML-141d	1240 m	"
ML-141e	1240 m	"
ML-141c	1232 m	"
ML-141b	1225 m	"
ML-141a	1220 m	"
ML-18c	1188 m	Lacustrine sediment/Till contact
ML-18d	1180 m	"
BH-135c	1180 m	"
BH-135b	1175 m	"
ML-18e	1165 m	"
T-151f	1165 m	"
T-150b	1162 m	"
BH-135d	1158 m	"
BH-1351	1158 m	"
T-149b	1158 m	"
BH-135j	1155 m	"
T-151e	1155 m	"
BH-135k	1152 m	"
BH-135g	1150 m	"
T-150a	1150 m	"
T-151b	1150 m	"
T-151c	1150 m	"
ML-18f	1145 m	"
ML-18g	1145 m	"
BH-135i	1145 m	"

*Localities given in Appendix G.

Drainage of the lake was initially to the east, along the present course of Gros Ventre Creek to the Elkwater-Battle meltwater channel and eventually to the Qu'Appelle- Assiniboine drainage system developing to the east (see Fluvial Section). The lake level at this time was at its maximum elevation.

The absence of strandlines, phytoplankton, and downcut deltas suggests that Lake Gros Ventre was an event of limited duration. The lake's continued existance was dependent upon the rate of glacial ablation along the northern and western shorelines remaining in excess of the rate of retreat of the southern portion of the ice sheet, which blocked Medicine Lodge Coulee and thus impounded the waters. This situation could not have remained stable for an extended period of time during glacial retreat.

Continued isostatic recovery and ice retreat constantly altered the areal dimensions of the lake. When the ice front retreated from Medicine Lodge coulee, the lower outlet at 1140 m became exposed, causing rapid drawdown to this level. Shortly thereafter, continued ice retreat along the Bullshead Creek valley permitted lake waters to flow northward at an even more favourable gradient. As a result of the opening of these outlets, the lake split rapidly into two distinct bodies of water, one draining south, the other northwest. The absence of strandlines indicates that complete drawdown was rapid, and the former lake bed was soon occupied only by two streams, Medicine Lodge and Bullshead

Creeks. These streams continue to drain the area today.

c) Pakowki Basin Lakes, Phase B retreat.

Continued retreat of the Phase B ice sheet exposed the Pakowki Basin, resulting in the development of a number of lakes in the area. These lake limits were recognized primarily through survey of aerial photographs and changes of sediment type and texture observed in the field. The presence of deltas developed on tributary streams that were subsequently exposed, and wave-washing effects noted on some sediments served as additional evidence. Distinctive diatom assemblages were found to be associated with several lake phases, and were used to assign lacustrine silts to specific phases once the relationships between diatom-bearing sediments and the beach sands marking the lacustrine limits were clear.

Due to the subsequent development of lakes in the northern portion of the basin during the Phase C glaciation and subsequent retreat, the Phase B lacustrine events can be recognized only in the southern portion of the basin. Five distinct lake phases -- Pendant d'Oreille, Canal Creek I and II, Hanson Creek, and Gahern -- are exposed in this area (Figure 30 and Table 13).

The earliest lake known in the area, Lake Pendant d'Oreille, achieved a maximum elevation of 962 m as indicated by lacustrine beach sediments (Table 14). The maximum elevation of 962 m was recorded from non-fossilferous sands in the vicinity of Pendant d'Oreille

FIGURE 30

LAKE STAGES IN THE PAKOWKI BASIN, PHASE B RETREAT

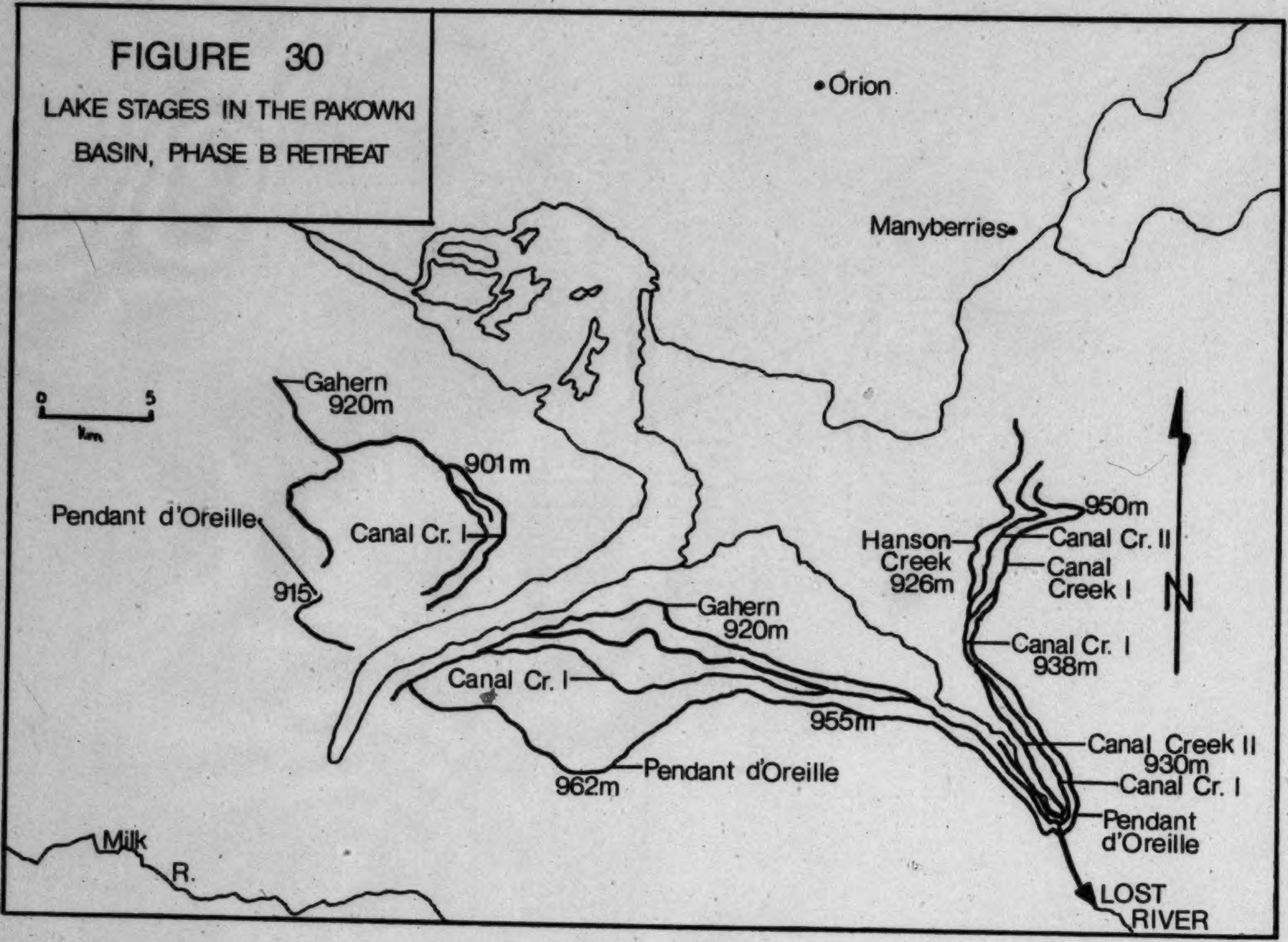

Orion
Manyberries
0
5
km
Gahern
920m
901m
Pendant d'Oreille
Canal Cr. I
915
Gahern
920m
Canal Cr. I
955m
962m
Pendant d'Oreille
Milk
R.
Hanson
Creek
926m
950m
Canal Cr. II
Canal
Creek I
N
Canal Cr. I
938m
Canal Creek II
930m
Canal Cr. I
Pendant
d'Oreille
LOST
RIVER

TABLE 13

Phase B Lacustrine Stages, Pakowki Basin

Name	Maximum Elevation	Outlet and Elevation	Diatom Assemblage
Pendant d'Oreille	962 m	Lost River 935 m?	Unknown
Canal Creek I	950 m	Lost River 930 m	*Asterionella-* *Melosira italica*
Canal Creek II	940 m	Lost River 925 m	*Melosira italica*
Hanson Creek	928 m	Lost River 922 m	Unknown
Gahern	920 m	Lost River 920 m	*Melosira granulata-* *Fragilaria crotonensis*

TABLE 14

Limits of Lake Pendant d'Oreille

Locality*	Elevation	Feature
CC-184c	962 m	Beach Sediments
CC-184a	955 m	Wave-washed till
CC-184b	952 m	Beach Sediments
CC-180f	950 m	Wave-washed till
CC-180e	947 m	Beach Sediments
CC-179c	944 m	Wave-washed till
CC179b	940 m	Beach Sediments
CC-180c	938 m	Beach Sediments
CC-180a	935 m	Beach Sediments
CC-179d	935 m	Beach Sediments
EK-231c	925 m	Lacustrine-till contact
EK-231b	922 m	Lacustrine-till contact
EK-231a	915 m	Lacustrine-till contact

*Loacaities given in Appendix G

(locality CC-184c). No organic material was discovered in any Pendant d'Oreille sediments. Due to the sandy texture of the sediments, no ice-rafted material could be recognized.

Drainage of this stage was through the Lost River channel to the southeast. Since the elevation of the highest lacustrine sediments in this area is 935 m, this figure is probably representative of the elevation of the outlet at this time. The proglacial nature of the lake and the subsequent development of the Phase C lakes mean that no estimate of the lake's northernmost limit can be obtained.

The difference in elevation between the highest lacustrine sediments and the outlet indicates that the lake's water surface was tilted relative to present sea level. This deformation was most probably produced by isostatic depression induced by the Phase C ice sheet. Since the position of the lake's northern border is unknown, the difference of 27 m between the elevations of the highest sediments and the outlet is only a minimum estimate of the total amount of isostatic depression.

A pair of closely-spaced bands of lacustrine beach sands are present at several localities along the valleys of Canal Creek and Hanson Creek (Tables 15 and 16). The higher lacustrine phase, as delineated by these sediments, is here designated Lake Canal Creek I, while the lower phase is termed Lake Canal Creek II.

TABEL 15

Limits of Lake Canal Creek I

Locality*	Elevation	Feature
MB-176i	950 m	Beach Sediments
MB-176j	948 m	"
MB-176k	944 m	"
MB-176m	942 m	"
MB-177a	940 m	"
MB-177b	938 m	Downcut Delta
MB-177c	938 m	Wave-washed till
CC-86a	938 m	Beach Sediments
CC-86b	938 m	"
CC-86d	938 m	Wave-washed till
MB-178e	936 m	"
MB-178a	935 m	Beach Sediments
MB-178d	935 m	"
CC-86c	935 m	"
CC-185g	935 m	Wave-washed till
MB-178f	933 m	Beach Sediments
CC-180d	933 m	"
CC-180c	932 m	"
CC-179a	931 m	"
CC-179c	930 m	"
CC-180a	930 m	"
PK-192a	914 m	Lacustrine/Till contact
PK-192b	909 m	"
PK-192c	908 m	"
PK-192d	901 m	"

*Localities given in Appendix G.

TABLE 16

Limits of Lake Canal Creek II

Locality*	Elevation	Feature
MB-176h	940 m	Beach Sediments
MB-176j	938 m	"
MB-176k	936 m	"
MB-176l	935 m	"
MB-178b	935 m	"
MB-178c	933 m	"
MB-178d	933 m	"
CC-185f	932 m	Wave-washed till
MB-178f	930 m	"
CC-181a	930 m	Beach Sediments
CC-179a	928 m	"
CC-181b	928 m	"
CC-181c	928 m	"
CC-180b	927 m	"
CC-179c	925 m	"
CC-179a	925 m	"

*Localities given in Appendix G.

The sediments of the two lake phases are largely silt and sandy silt, with the exception of the nearshore areas. Occasional laminar bedding was noted, but most of the sediments are structureless. Dropstones are conspicuous by their absence in sediments of Lake Canal Creek II, possibly indicating that the ice front did not form a portion of the border of this lake. Dropstones are present in silty sediments deposited in Lake Canal Creek I.

The continued decline of proglacial water levels which produced the Canal Creek I and II lacustrine stages was initiated by isostatic recovery, as indicated by the constant increase in elevation of the beach sediments with distance northward from the outlet (Tables 15 and 16). Downcutting of the Lost River outlet, as evidenced by the decrease in elevation of the lacustrine sediments at the channel's head, also contributed to the gradual lowering of water level in the basin.

The diatom assemblages present in the silts of both Canal Creek stages indicate oligotrophic conditions, approaching mesotrophy as the water level declined. Molluscan fauna was dominated by _Pisidium nitidum_, _P. casertaneum_, _Ferrissia kirklandi_, and terrestrial gastropods such as _Vertigo modesta_ and _Succinea sp._ The assemblage suggests a shallow lake, with some vegetation present (Leonard, 1959; Taylor, 1960; Herrington, 1962), and input of streams from the surrounding area. The presence of terrestrial gastropods does not necessarily indicate that the climate had moderated, as similar assemblages have been found in supraglacial lakes (Taylor, 1960, Westgate, 1964). However, the presence of a more complete pine woodland assemblage associated with Lake Wild Horse III to the southeast suggests that climatic amelioration following the Phase B deglaciation had occurred relatively quickly. A similar climatic shift prior to total deglaciation can be inferred from the molluscan assemblage noted in a supraglacial lacustrine deposit in North Dakota by Tuthill _et al_ (1964). Furthermore, it has been demonstrated through palynological studies (Wright, 1969) that glacial activity adjacent to a pine-dominated forest does not necessarily alter the vegatative community.

With the withdrawal of the ice front from the water's edge, isostatic recovery porceeded rapidly. Temporary stabilization of the level of the Lost River outlet at approximately 922 m produced a short-lived, poorly-documented stage, Lake Hanson Creek, as indicated by the positions of sandy beach sediments and indistinct wave-scoured benches along the Lost River channel's northeastern margin (Table 17). Sediments of this lake level, exposed along the banks of Hanson Creek, are structureless, palaeontologically-barren silts. The difference between the outlet level and the maximum elevation of Lake Hanson Creek deposits is only 6 m, indicating that isostatic recovery was almost complete at the time of the lake's existence.

TABLE 17

Limits of Lake Hanson Creek

Locality*	Elevation	Feature
MB-176g	928 m	Beach Sediments
MB-176h	928 m	"
MB-176j	927 m	"
MB-176m	926 m	"
CC-181f	924 m	"
CC-181g	924 m	"
CC-181e	924 m	"
CC-181c	923 m	"
CC-179b	922 m	"
CC-181d	922 m	"

*Localities given in Appendix G.

The cessation of rebound resulted in the production of a stable lacustrine stage in the basin, Lake Gahern. The extent of this lake is recognized through the distribution of lacustrine beach sediments, downcut deltas on tributary streams, and wave-washed silts deposited during previous lacustrine events. These data are summarized in Table 18.

This lake, the lowest preserved from the Phase B retreat, was mesotrophic in nature as indicated by its diatom flora (Rawson, 1956; Bradbury, 1974). The sediments, most of which were silty in nature, also contained a sparse amount of the gastropods Lymnaea stagnalis, Helisoma sp., and Valvata tricarinata, as well as fragments of Pisidium sp. This assemblage is typical of low-energy lakes in boreal or sub-boreal forest areas (Tuthill et al, 1964).

The gradual increase of nutrient supply to the lakes of the Pakowki basin is reflected in the changes noted in the diatom assemblage (Table 19). This increase was due to the development of vegetation in the surrounding area, and the progressive decrease in the volume of nutrient-deficient glacial meltwater added to the lakes. Although this transition represents a major alteration in the lacustrine environment, it appears to have occurred over a limited time, as inferred from the poor development of fluvial deltas discharging into the lakes and the general absence of discernable lacustrine terraces. A similar environmental change, artifically-produced, was

TABLE 18

Limits of Lake Gahern

Locality*	Elevation	Feature
CC-180c	920 m	Beach Sediments
CC-180d	"	"
CC-185c	"	"
CC-185d	"	Wave-washed Till
CC-185e	"	Beach Sediments
CC-185f	"	"
PK-189a	"	Downcut Delta
PK-189b	"	Beach Sediments
PK-189c	"	"
PK-189d	"	Wave-washed Till
PK-189f	"	"
EK-230b	"	Wave-washed Till
EK-229a	"	Wave-washed Silts
EK-229e	"	Wave-washed Till

*Localities given in Appendix G.

TABLE 19

Summary of Environmental Characteristics, Pakowki Basin Lakes, Phase B Retreat.

Stage	Diatom Assemblage	Environmental Classification*
Pendant d'Oreille	Unknown	Proglacial (Cold, Oligotrophic)
Canal Creek I	*Asterionella-* *Melosira italica*	Cold, Oligotrophic
Canal Creek II	*Melosira italica*	Cold, slightly Mesotrophic
Hanson Creek	Unknown	Unknown
Gahern	*Melosira granulata* *Fragilaria crotonensis*	Cool, Mesotrophic

*Based upon the criteria of Rawson (1956), Bradbury (1974).

documented in Lake Washington, Wa. (Stockner and Benson, 1967). The absence of oligotrophic lakes developed over sedimentary bedrock on the Canadian Prairies, as indicated by the investigations of Rawson and Moore (1944), suggests that this nutrient-deficient condition is inherently unstable in a lowland environment. This conclusion is substantiated by the presence of oligotrophic lakes only at moderate to high elevations in the Rocky Mountains (Mozley, 1933). Thus, development of mesotrophic conditions occurred soon after deglaciation, implying that these Phase B retreat lakes had a very limited life span.

d) Pakowki Basin Lakes, Phase C retreat and Holocene.

The lake stages formed in the Pakowki basin immediately before, during, and after the Phase C retreat were controlled by a combination of isostatic recovery, meltwater input, and fluvial downcutting of outlets. On the bases of beach sediment positions, downcut deltas on tributary streams, and diatom assemblages, eight lacustrine stages can be recognized (Figure 31 and Table 20).

Lake Manyberries I formed during the Phase C maximum period in the Manyberries area. It was the highest of the northern basin lakes, reaching a maximum elevation of 952 m. The lowest elevation at which Lake Manyberries I shoreline sediments can be definitely recognized is 936 m, south of South Manyberries Creek (locality MB-176d). The pattern of nearshore sediment distribution (Table 21) suggests that Lake Manyberries I was confined to the

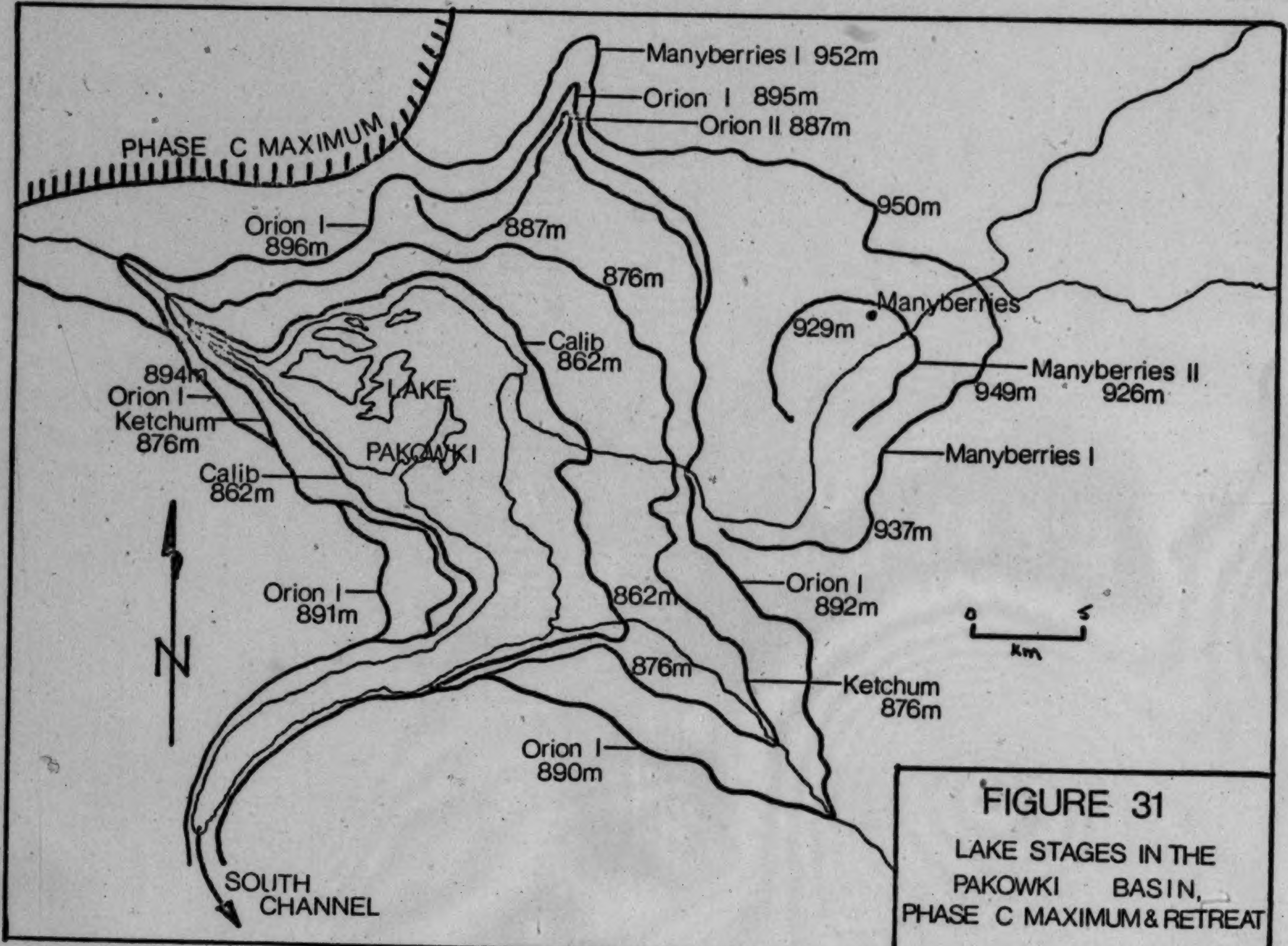

PHASE C MAXIMUM
Manyberries I 952m
Orion I 895m
Orion II 887m
950m
Orion I
896m
887m
876m
Manyberries
929m
Manyberries II
926m
949m
Manyberries I
937m
Calib
862m
LAKE
PAKOWKI
894m
Orion I
Ketchum
876m
Calib
862m
Orion I
891m
862m
Orion I
892m
0
5
km
876m
Ketchum
876m
Orion I
890m
SOUTH
CHANNEL

FIGURE 31

LAKE STAGES IN THE PAKOWKI BASIN, PHASE C MAXIMUM & RETREAT

TABLE 20

Phase C and Holocene Lacustrine Stages, Pakowki Basin.

Name	Maximum Elevation	Outlet and Elevation	Phytoplankton Assemblage
Manyberries I	952 m	936 m Streams connected to Lost River?	Melosira italica- Tabellaria- Navicula sp
Manyberries II	929 m	914 m Manyberries Creek	Melosira italica
Orion I	896 m	South Channel --890 m	Unknown
Orion II	887 m	South Channel --885 m	Fragilaria- Stephanodiscus
Ketchum	876 m	South Channel 876 m	Unknown
Calib	862 m	No Outlet	Microcystis
Post-Altithermal	850 m?	No Outlet	Unknown
Modern Lake Pakowki	858 m	No Outlet	Microcystis- Anabaena- Aphanizomenon

TABLE 21

Limits of Lake Manyberries I

Locality*	Elevation	Feature
MB-171a	952 m	Beach Sediments
MB-171b	952 m	"
MB-171e	952 m	"
MB-207d	952 m	"
MB-171c	950 m	Downcut Delta
OR-202f	950 m	Wave-washed Till
OR-206a	950 m	"
OR-206b	950 m	"
OR-206e	950 m	"
MB-207a	950 m	Beach Sediments
MB-207b	950 m	Downcut Delta
MB-207c	950 m	Beach Sediments
MB-171d	949 m	"
MB-207e	949 m	"
MB-13a	948 m	"
MB-171g	948 m	"
MB-171k	948 m	Wave-washed Till
MB-172a	947 m	Beach Sediments
MB-13b	946 m	"
MB-172b	946 m	"
MB-13c	945 m	Wave-washed Till
MB-13d	945 m	"
MB-172d	944 m	Beach Sediments
MB-174b	942 m	"
MB-174a	940 m	"
MB-176a	939 m	"
MB-174c	939 m	"
MB-174d	938 m	"
MB-174e	938 m	"
MB-174f	938 m	"
MB-176f	938 m	"
MB-176g	938 m	"
MB-176b	937 m	"
MB-176c	937 m	Downcut Delta
MB-176d	936 m	Beach Sediments
MB-176e	936 m	"

*Localities given in Appendix G.

northern portion of the Pakowki basin. The lake probably drained through a stream connecting to the Lost River outlet.

Due to the isolated nature of its position relative to the main basin, the Manyberries I basin displays a number of exposures showing a variety of sediment types and lithofacies. The basal unit is a structureless silty clay, which overlies outwash gravels and ablation till produced during the Phase B retreat (Sections MB-10, MB-12). This unit grades upwards into a complex series of laminated clays, irregularly-laminated silts, and sand sand interbeds. The entire sequence resembles the proglacial delta structures described by Church and Gilbert (1975) and Shaw (1975). The sand lenses, occasionally cross-bedded, were produced in the distributary channels of the delta. Silty laminated beds formed in the areas of the delta where distributaries were temporarily inactive. The presence of alternating sand and silt units at some localities suggests that flow in the distributaries was subject to a strong seasonal control. This is to be expected in a proglacial environment, where the ablation rate and hence the meltwater influx varies considerably throughout the year.

The prodelta sediments associated with these seasonally active distributaries are varved clays and silts. The coarser-grained silt laminae were produced in association with the distributary channel sands: similar members of varved couplets produced in other ice-marginal lakes have been associated with turbidity currents

PLATE 10a. Lake Manyberries I varves, Locality MB-11. The varves, consisting of alternating bands of light-coloured silt and dark-coloured clay, are regularly-laminated, indicating a distal position at the time of deposition.

PLATE 10b. Enlarged View of Varves, Locality MB-11. Minor irregularities along the bedding planes can be seen at this scale. See text and Figure 32 for further discussion.

COLOURED PICTURE

generated by meltwater input (Ashley, 1972; Banerjee, 1973). The distinct fining-upward sequences noted in many coarse laminae in varve couplets, as documented by Eden (1955), tends to support the turbidity-current hypothesis. Several distinct examples of fining-upward coarse laminae in varved sequences were noted in the sediments of Lake Manyberries I by the author (Figure 32). The finer-grained laminae were produced during periods of low water inflow, and commonly grade downward into the coarser-grained units. However, the upper contacts of the fine-grained laminae are sharp, indicating truncation by the water flow out of which the coarser-grained material settled. This observation also supports the conceptualized turbidity-current origin of the varved deposits.

A number of varved units could be correlated between exposures in the basin, indicating that these events were not highly localized. No attempt to use the varves for chronological purposes was made. Although the varves of some lakes have been demonstrated to be strictly seasonal in nature (eg. Ashley, 1972), other lakes have been shown to be capable of producing as many as nine couplets in a single season (Gilbert, 1975). Storm events are usually responsible for the formation of these "extra" varves. The probability of producing more than a single couplet in one year depends upon the size and depth of the basin, the amount of meltwater influx, and the climatic situation (Gilbert, 1975; R. Gilbert, Queen's University, personal communication, 1978). Thus, a confined, shallow basin such

FIGURE 32.

Internal structure of varves, Lake Manyberries I Sediments, Locality MB-11.

The Figure illustrates the textural variation and internal structure of two varves from Locality MB-11. Note the fining-upward coarse laminae, the variations in thickness of both coarse and fine laminae, and the erosional contact between fine and coarse laminae. These features all support the suggested turbidity-current mode of formation.

LEGEND

☐ Coarse-grained (high inflow) laminae

▨ Fine-grained (low inflow) laminae

5/7 Percentage sand/Percentage clay

Vertical Scale: 3 x natural

Horizontal Scale: natural

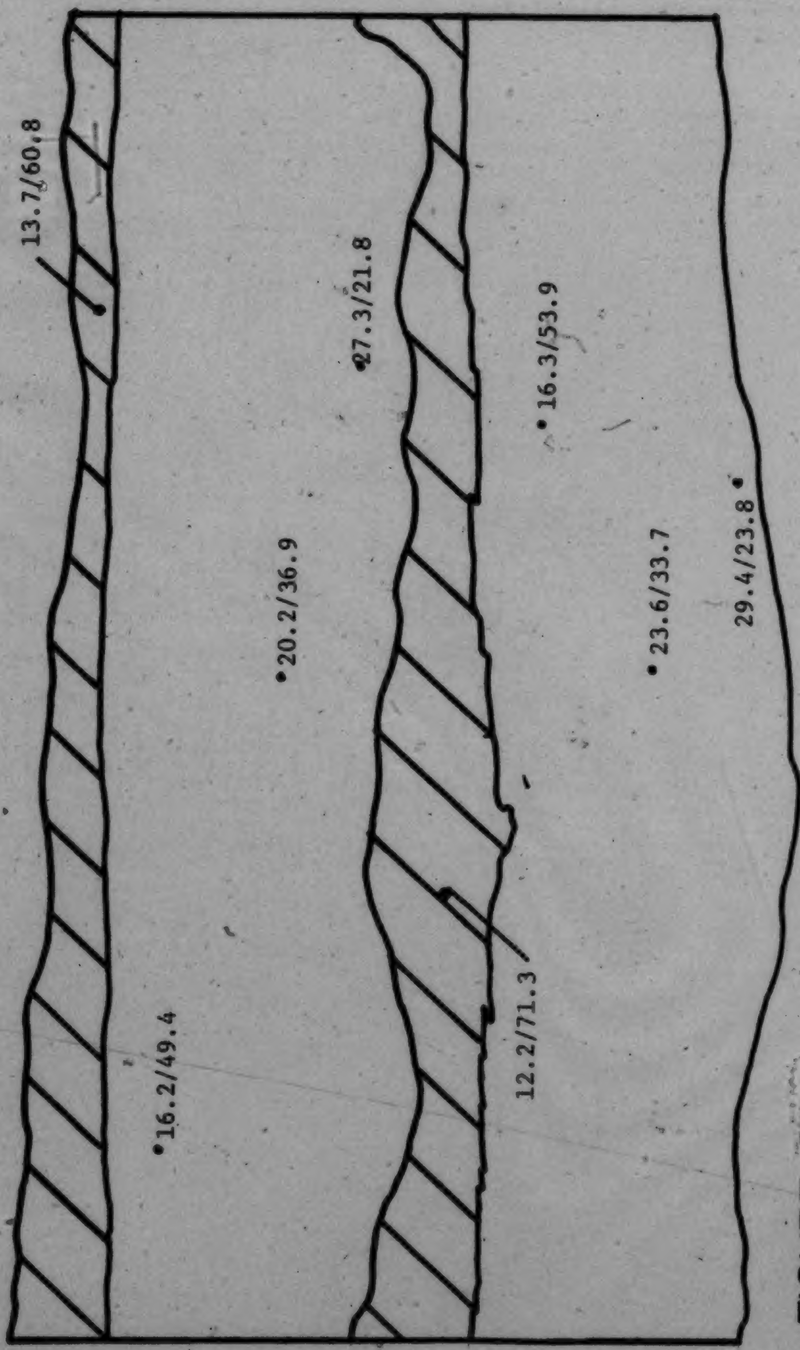

13.7/60.8
27.3/21.8
16.3/53.9
29.4/23.8
20.2/36.9
23.6/33.7
12.2/71.3
16.2/49.4

FIGURE 32

as Lake Manyberries I would be especially amenable to the formation of multiple couplets in a single season. Storm-produced couplets tend to vary in thickness, depending upon the severity of the specific event (Gilbert, 1975), and irregular variations in varve thickness were common in the Manyberries I sediments (eg. Section MB-11).

Many of the laminated sediments display contortions of various types. These features are especially notable at locality MB-11, where they are also delineated by the Manyberries (Glacier Peak G) volcanic tephra stratum. Four types of contortions were recognized in the sand and silt: side load contortions, foreset undercuts, slumping, and recumbent drag-folds. These features are illustrated in Figure 33.

Side-load contortions are found in silts and clays overlain by deltaic sand. The contortions take the form of a series of small overturned folds and crenulations. In areas closer to the delta front, as indicated by coarser-grained sediment and thicker laminations, minor low-angle reverse thrust faults were also present. These structures are believed to have been produced by the application of a deltaic sand load adjacent to the distorted clay and silt (McKee and Goldberg, 1969).

Foreset undercut structures result when the foreset beds of deltas are eroded at the base by backflow from turbidity currents. These irregular crenulations are always found adjacent to thick varve

FIGURE 33.

Contortion structures in Varved Sediments, Lake Manyberries I, Locality MB-11.

The Figure illustrates the four basic types of contortions observed at this locality.

a: Side-Load Contortions

b: Foreset Undercut Structures

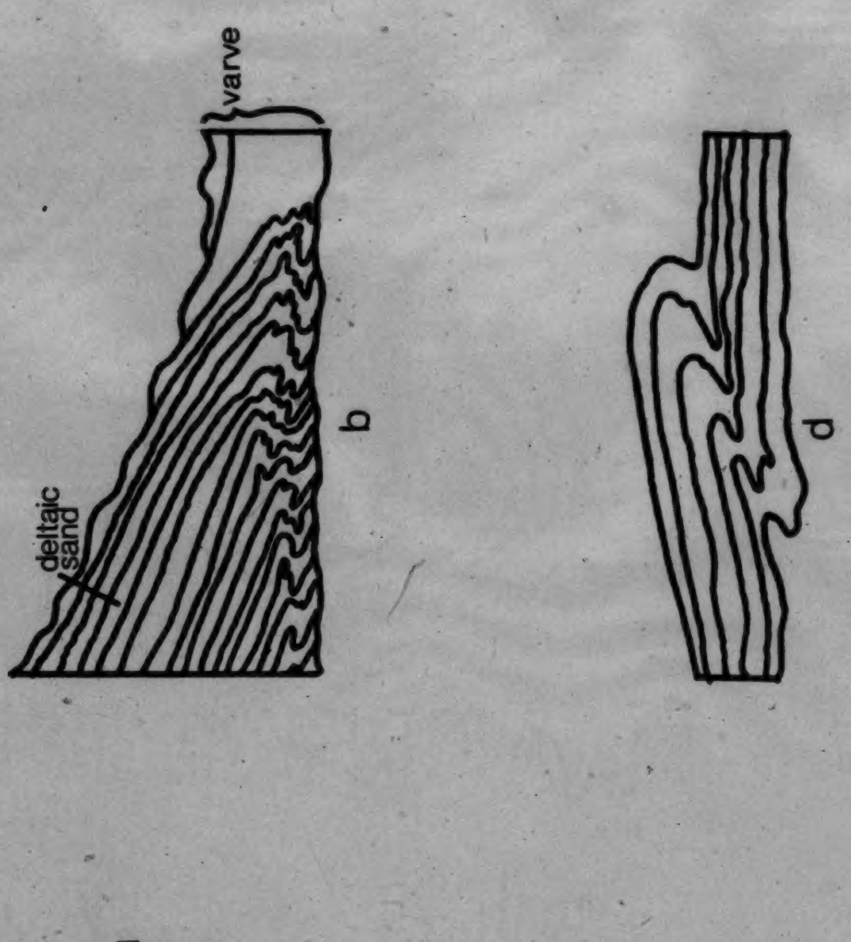
c: Slump Structures

d: Recumbant Drag-Folds

See text for further discussion.

Vertical Scale; 3 x natural

Horizontal Scale: Natural


varve
deltaic sand
b
d
sand
silt
a
c

couplets, and occur only in sand units. Similar structures have been produced by the undercutting of steeply-dipping sand beds in laboratory experiments (McKee and Goldberg, 1969)

Slump structures were present in several prodelta sedimentary units, but were less common than undercut structures. The sand units which had slumped were recognized by the irregular changes in thickness displayed by the laminae. The cause of slumping is believed to be the buildup of saturated sand concentrations at the heads of deltas during high meltwater flow events. Subsequent downslope movement under gravity produces the distortions, and also acts to initiate the turbidity currents responsible for the production of varves.

The fourth type of contortion observed is the recumbent drag-fold, produced by the movement of sediment-saturated currents over beds of sand or sandy silt (McKee and Goldberg, 1969). Minature examples of this type of distortion were observed in some coarse-grained varve laminae, and in distributary channel sands. These occurrences indicate that the currents responsible for the production of the drag folds may be either turbidity flows or sudden meltwater floods.

Many of the contortions displayed have been produced by the combined actions of two or more of these processes. Such compound features are difficult to catagorize, but the sedimentary association where they are located usually provides a clue as to the processes involved. All of the silt and clay contortions were produced by the loading in some manner of prodelta sediments. There is no evidence suggesting that any of these structures were formed by collapse subsequent to the melting of ice at depth, indicating that Manyberries I was not a supraglacial lake. The prevalence of dropstones in the lower strata also supports a proglacial rather than a supraglacial origin.

The phytoplankton assemblage of Manyberries I is oligotrophic in nature, dominated by _Melosira italica_, _Tabellaria Sp_., and _Navicula amphibola_. This assemblage resembles that found in subarctic lakes (Bradbury, 1974). Few molluscs were found, the only identifiable fragments belonging to the gastropod species _Gyralus similaris_, _Valvata tricarinata_, and _Amnicola limosa_. This assemblage is found in periglacial areas, although it is not confined to these regions (Taylor, 1960).

Since the ice front during the Phase C maximum followed the Etzikom moraine, to the north of the Pakowki basin, ice could not have been the cause of the confinement of Lake Manyberries I. Isostatic depression, however, could result in the production of a shallow basin immediately adjacent to the Phase C glacial front. The southern portion of the basin, where the Lost River outlet was located, would thus be elevated above the Manyberries I area. Estimates of the amount of isostatic depression induced by the Phase C ice sheet correspond fairly closely to the areal configuration of the Manyberries I sediment exposures. The derivation of the amount of isostatic depression is discussed in the section describing isostatic recovery.

Isostatic uplift during the Phase C retreat eventually isolated the Manyberries basin, producing the short-lived Manyberries II lacustrine stage. The uplift of the surrounding area caused this lake to drain rapidly to the main basin through Manyberries Creek. The only sediments present are structureless sandy silt units (Table 22). Recognition of the areal extent of this lake is difficult, due to the nature of its existence. However, it is estimated to have had a maximum depth of 15 m. The diatom assemblages are characterised by very low populations and diversities, and are heavily dominated by Melosira italica. The assemblage considered independent of its situation suggests an oligotrophic lake, very similar to Lake Manyberries I. The low diversity, however, suggests that this assemblage is a remané thanatocoenosis, derived from the underlying Manyberries I sediments.

Continued uplift in the northern part of the Pakowki Basin provided the impetus necessary for meltwater to flow at a favourable gradient towards the south. This caused the water level in the basin to decline and the shoreline to retreat southward, resulting in the formation of three lake levels in the basin: Orion I, Orion II and Ketchum.

Evidence for the existence of these lakes is somewhat fragmentary. Changes in sediment texture, as investigated on the ground and interpreted from aerial photographs, are the main form of evidence.

TABLE 22

Limits of Lake Manyberries II

Locality*	Elevation	Feature
MB-12a	929 m	Beach Sediments
MB-172e	926 m	Wave-washed Silts
MB-172f	924 m	"
MB-172h	920 m	"
MB-172i	918 m	Beach Sediments
MB-172j	916 m	"
MB-173a	914 m	Wave-washed Silts
MB-173b	914 m	Beach Sediments
MB-173c	914 m	Wave-washed Silts

*Localities given in Appendix G.

PLATE 11a. Truncation of Lake Manyberries I varves by sediments of Lake Manyberries II, Locality MB-10. The truncation is visible at the upper left of the picture. Scale 1:20.

PLATE 11b. Enlarged view of Truncation of varves, Locality MB-10. Note the irregularity of the varve bedding planes, and the structureless nature of the Manyberries II sediments. See text for discussion.

COLOURED PICTURE

The presence of belts of sand at 896 m, 887 m, and 876 m in the Orion area is taken to indicate that these elevations marked the level of former lake beaches or delta development (Tables 23, 24, 25). Several of the northern tributaries to Lake Pakowki have downcut previously-formed deltas; the elevations of these deposits, when correlated, agree with the lake levels postulated from the sand-rich belts. Other fluvial deposits in the area show a general coarsening-upward pattern, associated with the gradual shrinking of the water body and the consequent decline in base level and increase in stream gradient.

This continuum of lakes was probably mesotrophic in nature. Only one lake, Orion II, is represented by phytoplankton-bearing sediment. The assemblage, dominated by _Fragilaria crotonensis_ and _Stephanodiscus sp._, is typical of mesotrophic conditions (Rawson, 1956). The only mollusca recovered from sediments of any of the three lakes were specimens of _Vertigo modesta_, the terrestrial gastropod. These were found in nearshore sediments of all three lakes.

Uplift of northern portion of the basin, and the consequent southern flow resulted in the exhumation of the South Channel, a pre-existing valley connecting the Pakowki basin to the Milk River that had been filled with drift from previous glaciations. This channel had remained closed throughout the Phase B retreat period, as evidenced by the high levels which Phase B lakes in the basin had reached (Table 13). The elevation of the South Channel outlet was initially at 890 m, as

TABLE 23

Limits of Lake Orion I

Locality*	Elevation	Feature
OR-200b	896 m	Beach Sediments
OR-200e	896 m	"
OR-200g	896 m	Downcut Delta
OR-201d	896 m	Beach Sediments
OR-201e	896 m	"
OR-201f	896 m	"
OR-202e	896 m	"
OR-167c	895 m	"
PK-199e	895 m	"
OR-202a	895 m	"
OR-202b	895 m	"
OR-202c	895 m	"
OR-202d	895 m	"
EK-226f	895 m	"
EK-226a	894 m	"
EK-227a	894 m	"
EK-227b	894 m	Downcut Delta
EK-227c	894 m	Beach Sediments
EK-228a	894 m	Downcut Delta
EK-229a	893 m	Beach Sediments
EK-229b	893 m	"
EK-229c	893 m	"
EK-229d	892 m	"
PK-189f	891 m	"
PK-186a	890 m	"
PK-186c	890 m	"
PK-186d	890 m	"
PK-188e	890 m	"
PK-188f	890 m	"
PK-188g	890 m	"

*Localities given in Appendix G.

TABLE 24

Limits of Lake Orion II

Locality*	Elevation	Feature
OR-167a	887 m	Beach Sediments
OR-167b	887 m	"
PK-199h	887 m	"
PK-199j	887 m	"
PK-199k	887 m	Downcut Delta
OR-200a	887 m	Beach Sediments
OR-200b	887 m	"
OR-200c	887 m	"
OR-200f	887 m	"
OR-200g	887 m	"
OR-200h	887 m	"
OR-201b	887 m	Downcut Delta
OR-201c	887 m	Beach Sediments
OR-201e	887 m	Wave-washed Till
OR-201f	887 m	Beach Sediments
OR-167d	886 m	"
CC-180f	886 m	Strandline**
PK-199i	886 m	Beach Sediments
PK-188b	885 m	"
PK-188c	885 m	"

*Localities given in Appendix G
**Reported by Westgate (1964)

TABLE 25

Limits of Lake Ketchum

Locality*	Elevation	Feature
CC-86f	876 m	Beach Sediment
CC-86g	"	"
CC-87a	"	"
CC-87b	"	"
CC-87c	"	"
CC-87d	"	Wave-washed Silts
CC-87e	"	"
CC-87f	"	Beach Sediment
CC-87g	"	"
CC-87h	"	Wave-washed Silts
PK-186a	"	"
PK-186d	"	"
PK-188d	"	"
PK-188e	"	Wave-washed Till
PK-190a	"	"
PK-190c	"	Wave-washed Silts
OR-200b	"	Beach Sediments
PK-199a	"	"
PK-199j	"	"
EK-226d	"	Wave-washed Till

*Localities given in Appendix G

indicated by the position of the uppermost lacustrine sediment within the confines of the channel (Table 23). Since the lowest recorded Phase B lake, Lake Gahern, had a water plane elevation of 920 m, it is apparent that the South Channel outlet was not open at this time.

The South Channel lies south of the Phase C maximum position (the Etzikom moraine), and therefore could not have been blocked by Phase C drift. If the outlet was open during the Phase C maximum, Lake Manyberries I could not have maintained its minimum level of 936 m, 46 m above the level of the highest South Channel outlet sediment. Thus, the only outlet for Lake Manyberries I was the Lost River channel. The maximum level of Lake Orion I, 896 m, was below that of the Lost River (920 m), thus effectively closing this outlet. Consequently, the only outlet remaining functional was the South Channel. The uppermost lacustrine sediment in the South Channel has been correlated to Lake Orion I, as has been discussed previously.

Each of the Phase C lakes was successively lower in elevation, as isostatic recovery diminished and downcutting of the South Channel proceeded. A comparison of the maximum elevation at which sediments of each successive stage are found and the elevations of the outlet (Table 20) reveals that isostatic recovery had ceased completely when the Ketchum level was attained.

Continued climatic amelioration during the early Holocene resulted in a gradual decrease in the amount of rainfall received by the areas adjacent to the Pakowki basin, and in consequence the volume of water being removed from the lake by evaporation exceeded the fluvial and atmospheric input. This situation resulted in the decline of the water level in the basin below the level of the floor of the South Channel outlet, isolating the basin. This phase of the basin's history is referred to as Lake Calib (Table 26). The lake waters carved a well-defined bluff at 862 m around most of the shoreline, and proceeded to gradually become more saline. This trend is noticeable in the phytoplankton assemblage, which is dominated by *Microcystis sp*. The presence of *Chaetoceros sp* and *Suricella sp* suggests a salimity of 1000-5000 ppm (Rawson and Moore, 1944). Fragments of *Pisidium variabile* and *P. casertaneum* were found in the upper portion of the Calib deposits. Both of these species have a preference for shallow, mud-substrate areas with limited current (Herrington, 1962). Several terrestrial gastropods were also observed.

Water completely disappeared from the Pakowki basin during the subsequent warm, dry period known as the Altithermal (Antevs, 1948). In Western Canada, this period appears to have persisted from 8500 B.P. until 7000 B.P. (Ritchie, 1976; Waters, 1979; further discussion in Palaesols and Related Palaeoenvironments section). As general climatic cooling began after 7000 B.P., and as the amount of rainfall increased, the Pakowki basin began once more to fill with

TABLE 26

Limits of Lake Calib

Locality*	Elevation	Feature
CC-86e	862 m	Wave-cut Bench
CC-185a	"	"
CC-185b	"	"
CC-185c	"	"
CC-185d	"	"
CC-185e	"	"
CC-185f	"	"
CC-185g	"	"
PK-186a	"	"
PK-186b	"	"
PK-186c	"	"
PK-186d	"	"
PK-188a	"	"
PK-188b	"	"
PK-188c	"	"
PK-188d	"	"
PK-188e	"	"
PK-188f	"	"
PK-188g	"	"
PK-199a	"	"
PK-199b	"	"
PK-199c	"	"
PK-199d	"	"
PK-199e	"	"
PK-199f	"	"
PK-199g	"	"
PK-199h	"	"
PK-199i	"	"
PK-199j	"	"
PK-199k	"	"

*Localities given in Appendix G

water, covering deltas built by streams during the dry period immediately prior to the altithermal. One post-Altithermal lake stage, which resulted in the alteration of the broad delta built by water issuing from Etzikom Coulee, can be recognized by its subaqueous features, as seen on aerial photographs. The shallowness of the modern Lake Pakowki enables features of the former post-Altithermal lake to be recognized, and its elevation determined at approximately 850 m.

Currently, the Pakowki basin is occupied by Lake Pakowki, a swampy body of water with a water level of 858 m. The phytoplankton flora of the lake is a typically eutrophic, slightly saline-indicating assemblage, dominated by Microcystis sp. The basin has no outlet and input is intermittant. Although the lake appears to be increasing in volume over the long term, a decline in the water level has occurred since the lake was discussed by Dawson (1875).

e) Many Islands Lake

A brief reconnaissance of the Many Islands Lake area revealed only one lake level higher than the present lake surface. A well-developed bluff at 725 m surrounds the lake, and represents a former shoreline probably chronologically equivalent to the Calib stage in the Pakowki Basin. Conditions during the formation of the upper Many Islands Lake appear to have been similar to those during Lake Calib's existence. No flora or fauna were recovered from the lake sediments.

The absence of additional high-level shorelines around Many Islands Lake suggests that no proglacial basin was present here.

TABLE 27

Summary of Environmental Characteristics, Pakowki Basin Lakes, Phase C Maximum and Retreat.

Stage	Diatom Assemblage	Environmental Classification*
Manyberries I	*Melosira italica*- *Tabellaria*- *Navicula*	Cold, Oligotropic
Manyberries II	*Melosira italica***	Cold, Oligotrophic?
Orion I	Unknown	Unknown
Orion II	*Fragilaria*- *Stephanodiscus*	Cold, Mesotrophic
Ketchum	Unknown	Unknown
Calib	*Microcystis*	Cool, Eutrophic
Post-althithermal	Unknown	Unknown
Modern Lake Pakowki	*Microcystis*- *Anabaena*- *Aphanizomenon*	Cold, Eutrophic

*Based upon the criteria of Rawson (1956), Bradbury (1974).

**Possibly reworked from Manyberries I sediments.

This conclusion concurs with the deglaciation history as inferred from the distribution of the till deposits in the region. However, the necessarily superficial examination of the area does not merit excluding the possibility of higher lacustrine stages completely.

f) Supraglacial Lakes

Numerous small short-lived supraglacial lakes existed during the Phase B deglaciation.

The lake sediments are predominantly clay, with interbedded sand, silt, and marl present in very minor amounts. Contortions of laminar bedding in the silts were noted at some localities (eg. section BH-136, Appendix H). These features, as well as the high-angle normal faults also present in the sediments, indicate that distortion occurred due to removal of ice support at depth. Fossil assemblages were confined to molluscs: pelecypods noted were Pisidium spp., while the gastropods Stagnicola palustris, Gyraulus similaris, and Physa sp. were also present along with terrestrial gastropod species. Similar assemblages were noted by Westgate (1964).

None of the supraglacial lakes remained for a sufficient length of time to register a useful record of climatic fluctuations during the Phase B retreat, and none contained sufficient carbonate organisms for dating purposes. Consequently, they are of limited importance to a regional synthesis of Quaternary geology and climatology.

FLUVIAL DEPOSITS AND LANDFORMS

Fluvial activity in the Western Cypress Hills region related to glacial retreat events has carved several prominent meltwater channel systems. Three major periods of fluvial activity are recognized: an early phase, during which channels were developed around the Cypress Hills Plateau; a second phase, following the retreat of the Phase B glacier; and a final event, during the retreat of the Phase C glacier. These channel systems were connected to the lakes formed along the glacier margins, and acted as drainage channels for these bodies of water.

a) Plateau Rim Channels

The withdrawal of the Phase A glacier from the northern escarpment resulted in the development of a meltwater channel parallel to the glacier front and escarpment face. This channel, which presently contains Elkwater Lake and Battle Creek, is termed the Elkwater-Battle Channel. Meltwater produced during the Phase B retreat further scoured this drainage route, as well as carving another channel along the western flank of the plateau. This valley is occupied today by Medicine Lodge Creek.

During the initial stages of the Phase B retreat, the direction of flow in the northern channel, as indicated by imbricated gravels exposed along a poorly-developed terrace near Elkwater, was to the east. The position of the glacial front against the southwestern flank of the plateau prevented Lake Gros Ventre from draining to the south.

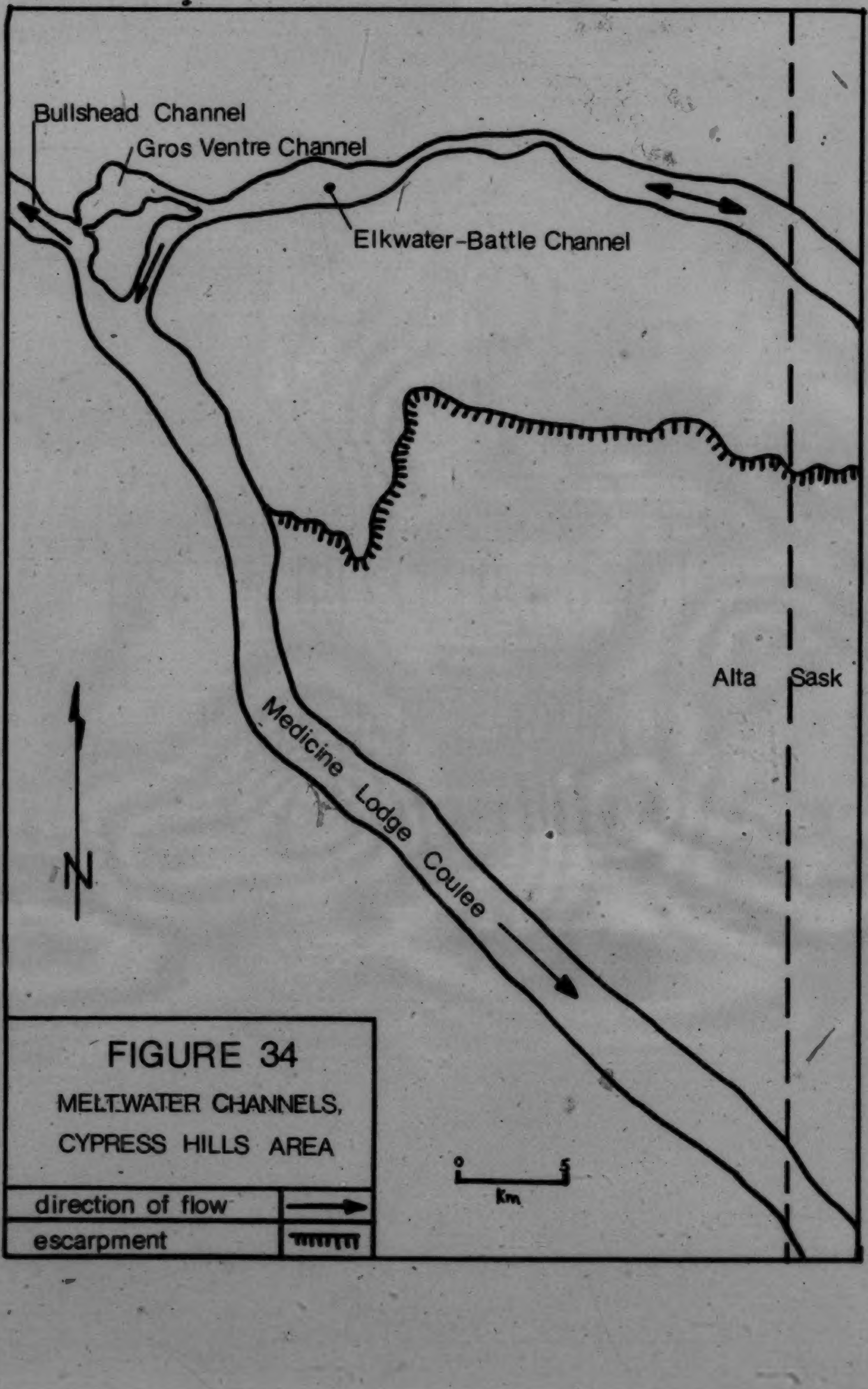

Bullshead Channel
Gros Ventre Channel
Elkwater-Battle Channel
Medicine Lodge Coulee
Alta
Sask
N
0
5
Km
direction of flow
escarpment

FIGURE 34

MELTWATER CHANNELS, CYPRESS HILLS AREA

The diversion of this basin's drainage to the east further augmented the water level in the Elkwater-Battle Channel, formation of the highest fluvial terrace being the result. This terrace, at an elevation of 1267 m in the Elkwater area, is quite poorly developed. This lack of distinctness is due to post-formational sediment and bedrock slumping. No palaeontological material relating to this river stage was discovered.

Continued retreat of the Phase B glacier opened the southeastern drainage route along Medicine Lodge Coulee. The gradient of this channel was sufficient to overcome the effects of glacio-isostatic depression. As a result, Lake Gros Ventre began to drain rapidly along this route, and the direction of flow in the Elkwater-Battle Channel reversed itself from east to west (Figure 35). The water level in the northern channel fell to the level marked by the second fluvial terrace, at 1240 m. No terraces could be discerned along Medicine Lodge Coulee, due to extensive slumping, and no fossils associated with this stage were discovered.

Continued glacial retreat gradually reduced the volume of water in the Elkwater-Battle and Medicine Lodge Channels. Along the northern flank, this decline is indicated by a series of indistinct water level positions (Figure 36). Both coulees were occupied by minor streams during relatively moist climatic intervals subsequent to the Phase B glaciation, including the present. Blocking of the Elkwater-Battle channel by slumping occurred c. 5100 B.P., resulting

FIGURE 35.

Palaeocurrent Directions, Elkwater-Battle Meltwater Channel.

The Figure illustrates the reversal of flow direction in the channel. Locality E-35f is associated with the uppermost level of the meltwater drainage system. Flow during this period was easterly, from Lake Gros Ventre.

Removal of the ice dam caused a change in flow direction to the west, as noted at locality E-35b. Fifty sand and gravel-sized clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale: 2.6 cm = 10 clast readings

FIGURE 35

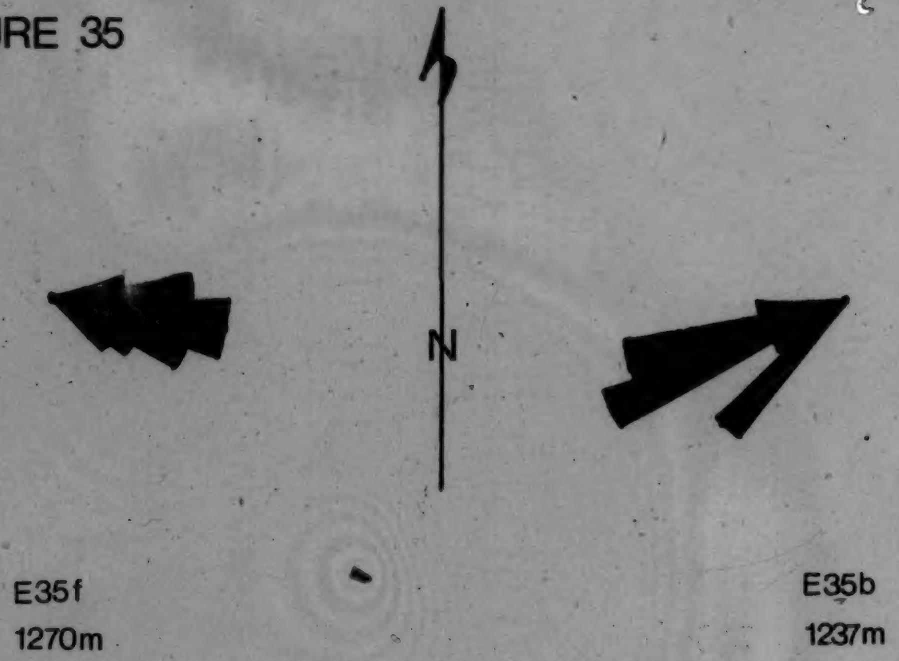
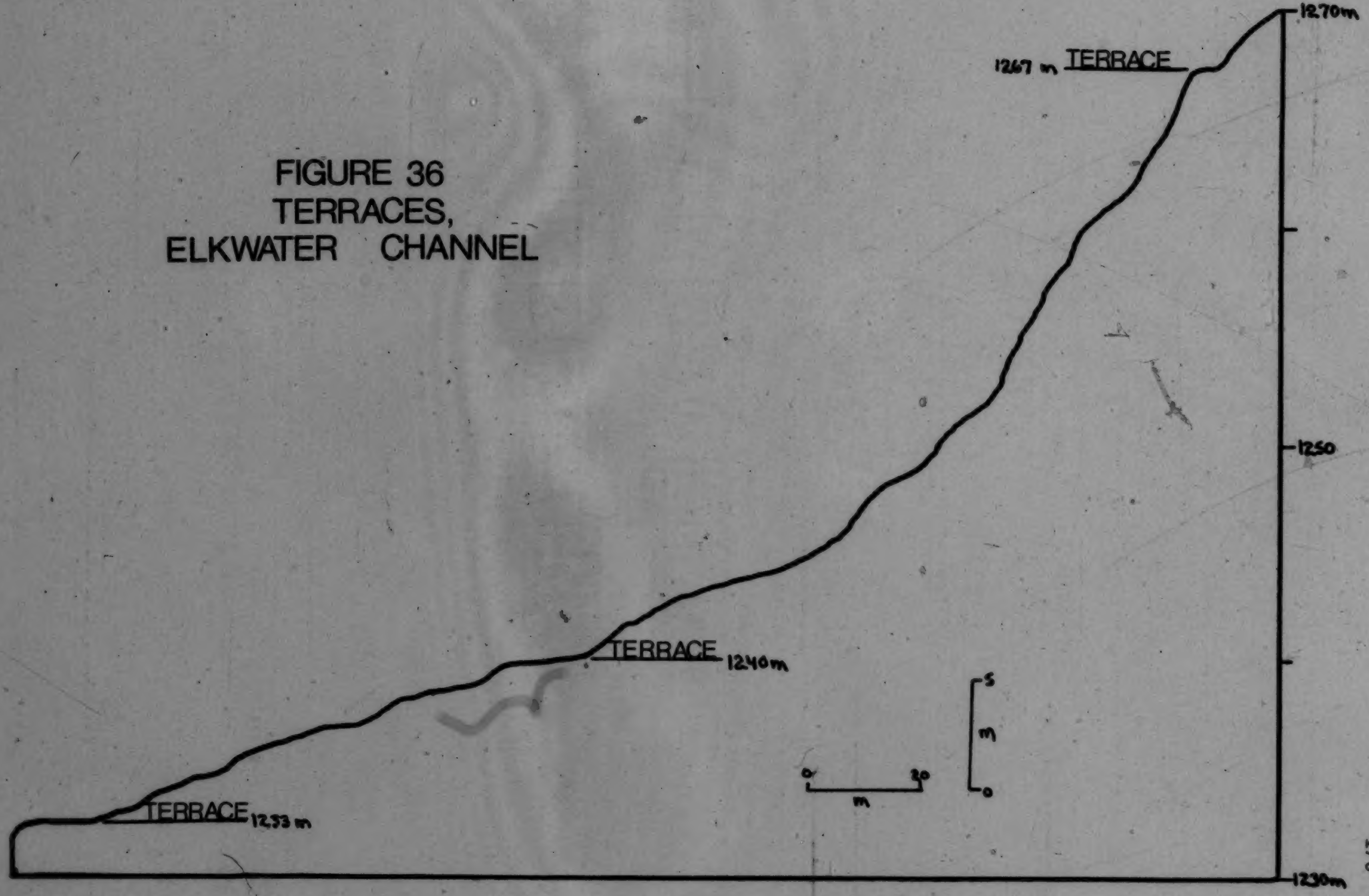


FIGURE 36
TERRACES,
ELKWATER CHANNEL


1270m
1267 m TERRACE
1250
TERRACE 1240m
TERRACE 1233 m
1230m
0 m 20
0 m 5

in the formation of Elkwater Lake (Terasmae, personal communication, Brock University, 1979). No lacustrine sediments older than the Holocene were noted in cores obtained by Terasmae.

b) Phase B retreat channels

These drainage routes were formed during the retreat of the Phase B glacier from the Wild Horse-Comrey area. The major channel, currently occupied by Lost River, connected the Pakowki basin to the Milk River and drained all of the lakes formed in this basin during the Phase B retreat. Downcutting of the spillway by the meltwater lowered the elevation of the drainage divide between the Pakowki basin and the Milk River system to an elevation of 917 m. Due to bedrock slumping, no terraces are discernable along the Lost River valley. Gravel imbrication in the few channel sediments preserved indicates that the direction of flow was consistantly to the southeast (Figure 37).

Several other minor channels developed parallel to the Lost River Spillway in the Wild Horse-Bain area. All of these spillways were utilized for very short periods, and none contain recognizable terraces. Flow in all these channels was to the southeast, eventually discharging into the Milk River drainage system. No organic material associated with any of these channels was found.

c) Phase C retreat channels

Retreat of the Phase C glacier from the Etzikom moraine caused the formation of a major meltwater channel between the ice front and the moraine. This spillway carried meltwater east from

FIGURE 37

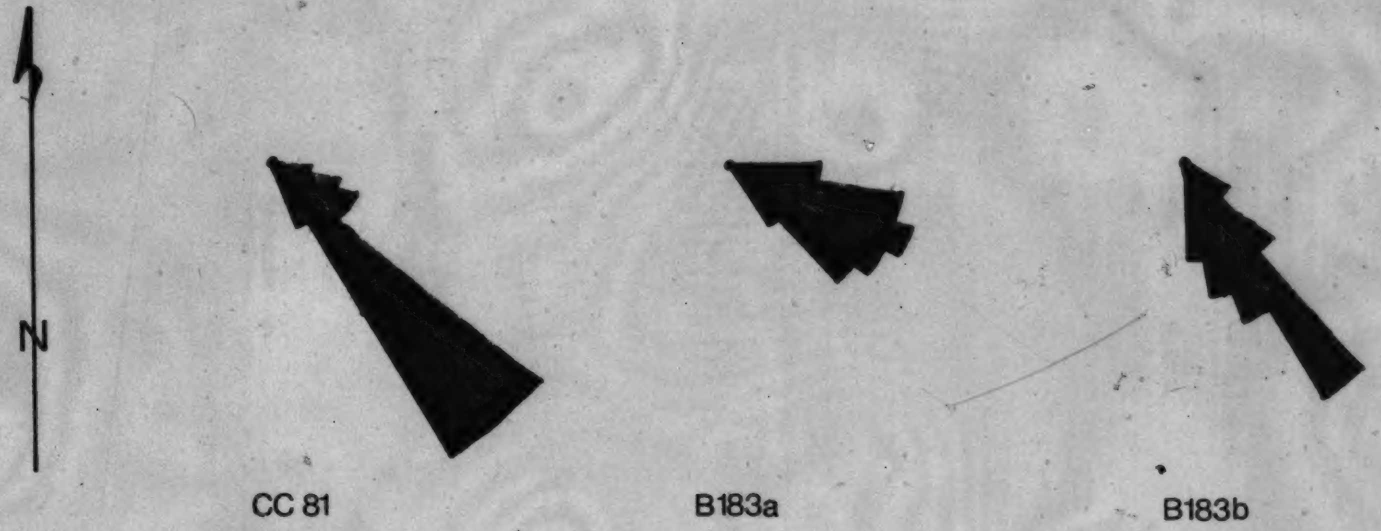
Southeast Palaeocurrents, Lost River Area Channels.

The Figure illustrates the southeastern flow directions common to all the channels paralleling the Lost River in the southeastern corner of the study region.

Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale 2.6 cm = 10 clasts

FIGURE 37


N
CC 81
B183a
B183b

the Seven Persons and Medicine Hat areas through Irvine and Walsh, eventually discharging into Lake Bigstick (Christiansen, 1979) and eventually to Lake Agassiz. The valley is currently occupied by portions of Seven Persons, Ross, Irvine, and Mackay Creeks (Figure 38). Although this channel was evidently utilized for a considerable period, as indicated by the development of tributary valleys currently occupied by Gros Ventre, Ross, McAlpine, and Mackay Creeks, no discernable terraces could be recognized and no organic material was found.

Continued retreat permitted the development of a complex system of tributaries to the main channel in the area west of Many Islands Lake. Other tributaries formed to the west of the study area, among them Chin and Forty Mile coulees. This drainage system continued to carry meltwater east until glacial retreat uncovered the South Saskatchewan channel north of the study area. When this event occurred, the channel system was abandoned except for the minor streams presently in existence.

FIGURE 38.

Phase C Retreat Meltwater Channels.

The Figure illustrates the major meltwater channel system in existance immediately after the retreat of the Phase C glacier from its maximum position. Drainage was generally towards the east.

LEGEND

⁓	Phase C Maximum Position
~~	Meltwater Channels
☰	Lake Mannyberries I
D	Dunmore
E	Elkwater
I	Irvine
M	Manyberries
O	Orion
S	Seven Persons

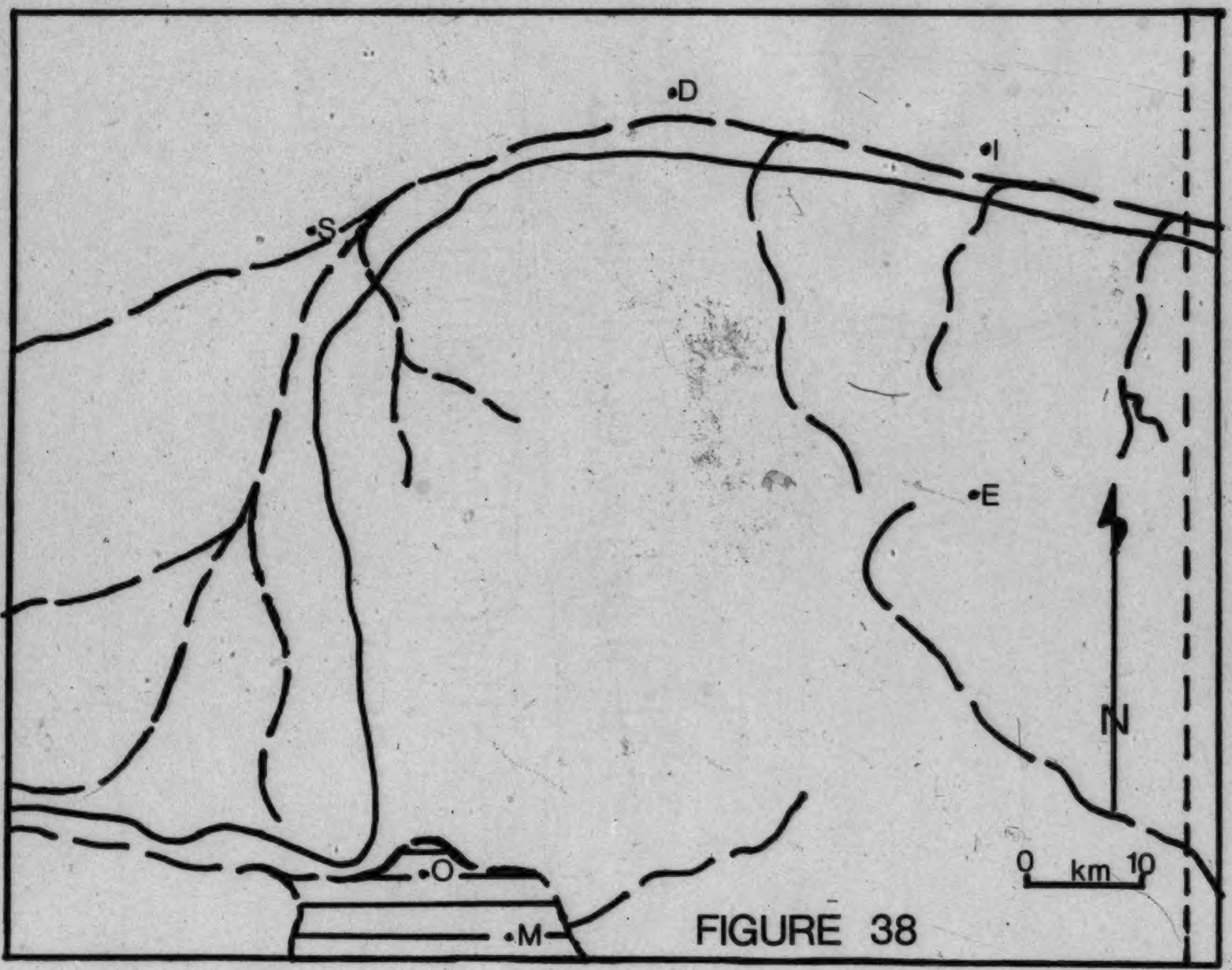

D
I
S
E
N
0 km 10
O
M

FIGURE 38

AEOLIAN DEPOSITS AND LANDFORMS

a) Loess

Several areas within the western Cypress Hills region are covered by thin blankets of silt and fine silica-rich sand. Chief among these is the portion of the Cypress Hills Plateau above the limit of the most extensive glaciation. The deposits on the plateau are composed largely of coarse silt, with the concentration of fine sand commonly approximating 20%. Measurements of textural distribution (Figure 39) fulfil the criteria of Doeglas (1949), Berg (1964), and Smalley (1966) for identification of the sediment as loess. At some locations (eg PL-88d) frost activity has elevated quartzite pebbles of the underlying Cypress Hills Formation, together with the coarse sand matrix, into the loess (Figure 40).

These aeolian deposits are characterised by quartz and heavy mineral concentrations higher than those of sediments from the surrounding areas. Feldspar and carbonate mineral percentages are correspondingly decreased in the loess (Figure 41). These mineralogical differences are caused by the simultaneous actions of two processes: weathering and aeolian sorting (Berg, 1964). Under the influence of temperate to subarctic climates, the decomposition rate of feldspars to sericite is in excess of the alteration of quartz. Consequently, feldspar grains exposed on the surface are more weathered and hence less likely to survive aeolian transport intact. The decomposition to sericite also effectively reduces the aerodynamic

FIGURE 39

LOESS
TEXTURES

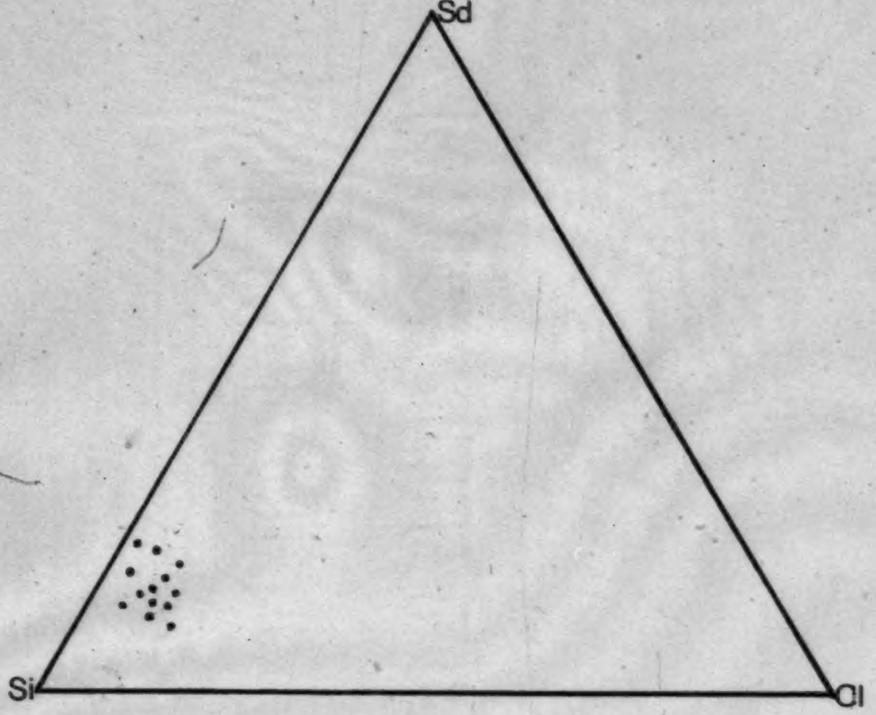


FIGURE 40

CYPRESS HILLS LOESS TEXTURES

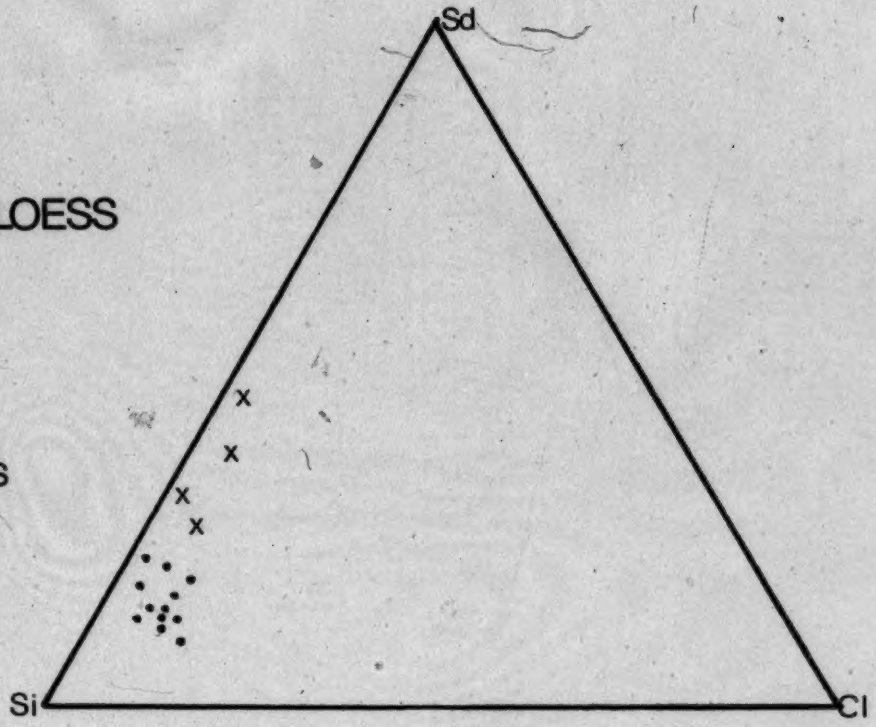
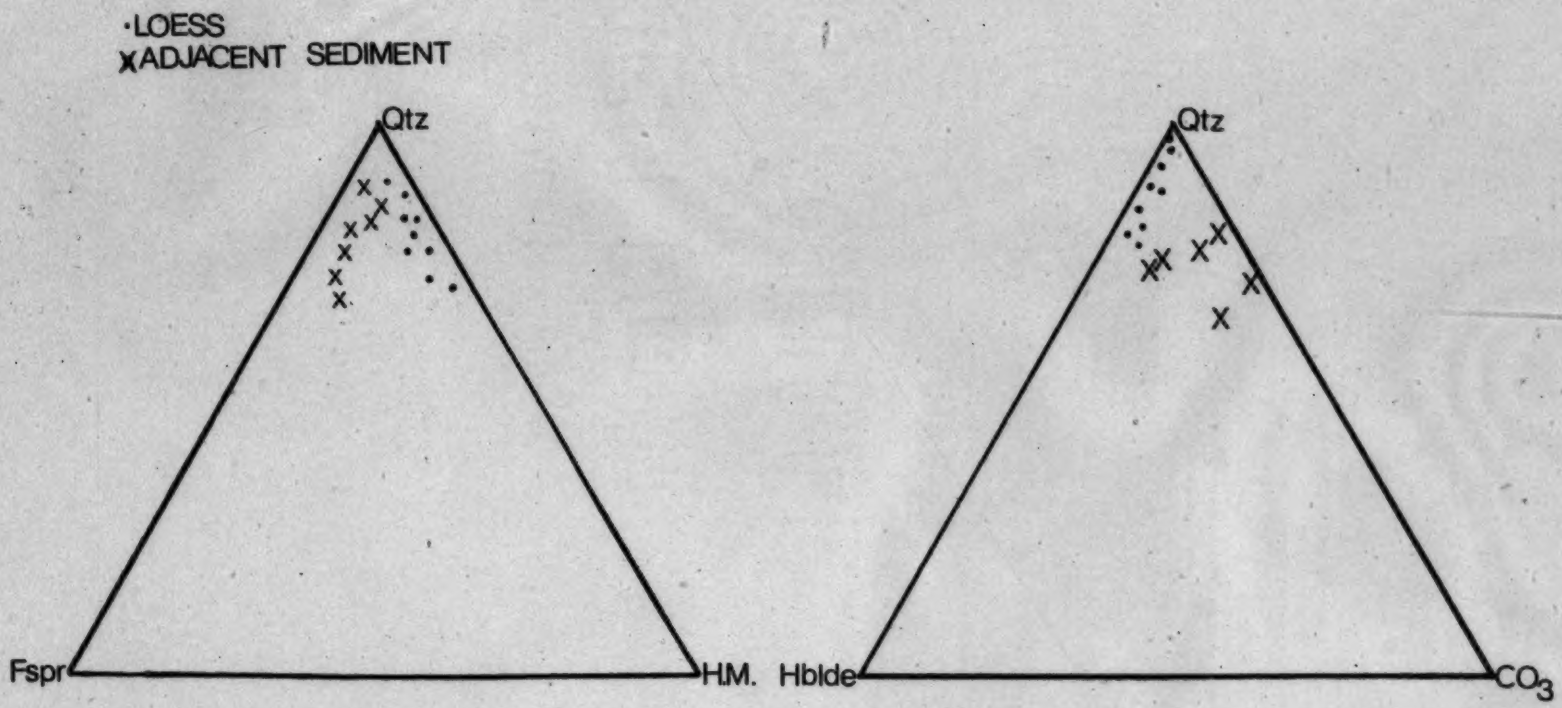


FIGURE 4I

LOESS MINERALOGY



efficiency of the wind by altering the shape of the grain. Simi-spherical grains, such as unaltered quartz, are more easily transported than platy clay mineral fragments (Bagnold, 1954). In addition, since the majority of the material comprising the loess was initially transported to the fringing areas by glacial action, the durability of quartz relative to feldspar meant that fewer quartz grains were reduced to clay-sized particles during transport. Consequently, more quartz silt was available for aeolian reworking upon deglaciation. The slight enrichment of the heavy mineral fraction of the loess relative to the Cypress Hills conglomerate and the lower formations surrounding the plateau is probably due to the depletion of carbonate and feldspar material during weathering and transport. The effectiveness of the sorting process, together with the absence of coarse-grained aeolian lag deposits and dunal features, suggests that the winds responsible for the deposition of the loess were of relatively low velocity. The aeolian sculpturing of some outcrops of the Frenchman and Ravenscrag Formations around the plateau's rim was produced by much stronger winds, and is most probably of pre-Quaternary age.

In undisturbed sections, the thickness of loess decreases exponentially from a maximum of 327 cm near the southwestern corner of the plateau (ML-225c) to zero in several localities along the provincial boundary. Similar exponential wedge-shaped patterns were noted by Krumbein (1937) in traverses perpendicular to the Mississippi River. David (1970) noted a similar pattern in bluffs flanking the South Saskatchewan River near Empress, Alberta, and termed the aeolian material "cliff-top deposits". He suggested that the wedge-like distribution was caused by the deposition of sediment by winds surmounting the bluffs from the river valley. The exponential decrease in thickness from west to east on the Cypress Hills plateau can be explained by this mechanism. In support of this suggestion, it was noted that the median grain size of the loess decreases regularly as the distance from the western escarpment increases (Figure 42).

The thickness of the deposits along the escarpment also give indications of the relative importance of wind activity from each direction (Figure 43). Since no wedge forms are found along the western flanks of Adams or Battle Creeks, it can be concluded that easterly winds were essentially non-existant during the Middle and Late Quaternary, when the loess formed. Similarly, the thick sediment wedges along the western and southern flanks of the plateau suggest that winds from these directions dominated. The pattern of loess distribution suggests a dominant mode of azimuth 245, with a secondary direction of 175. Along the northern flank of the upland, the aeolian sediments attain a maximum thickness of only 77 cm, thus indicating that northerly winds were not a significant factor in the development of the plateau. The Elkwater-Battle meltwater channel acted to

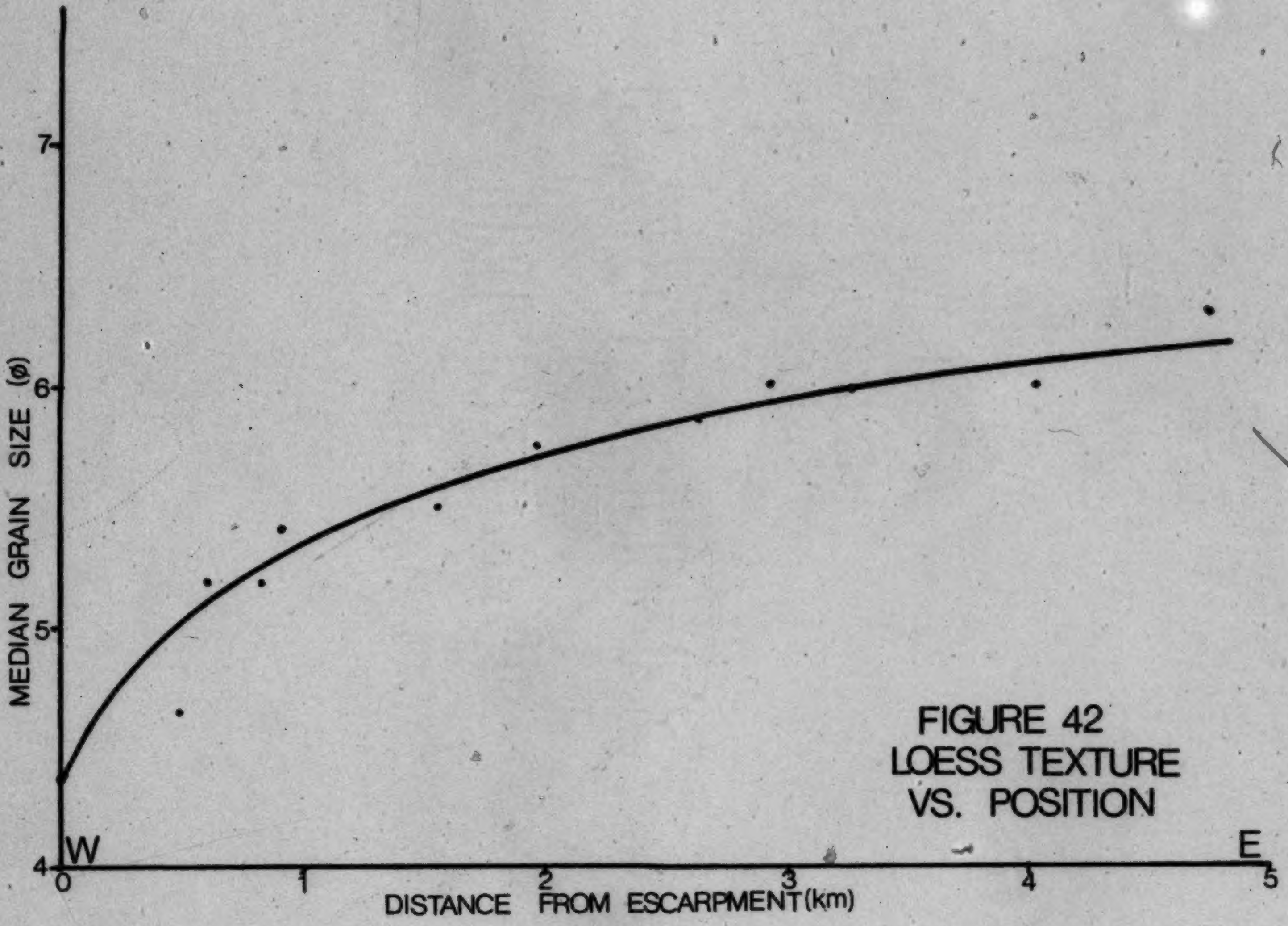
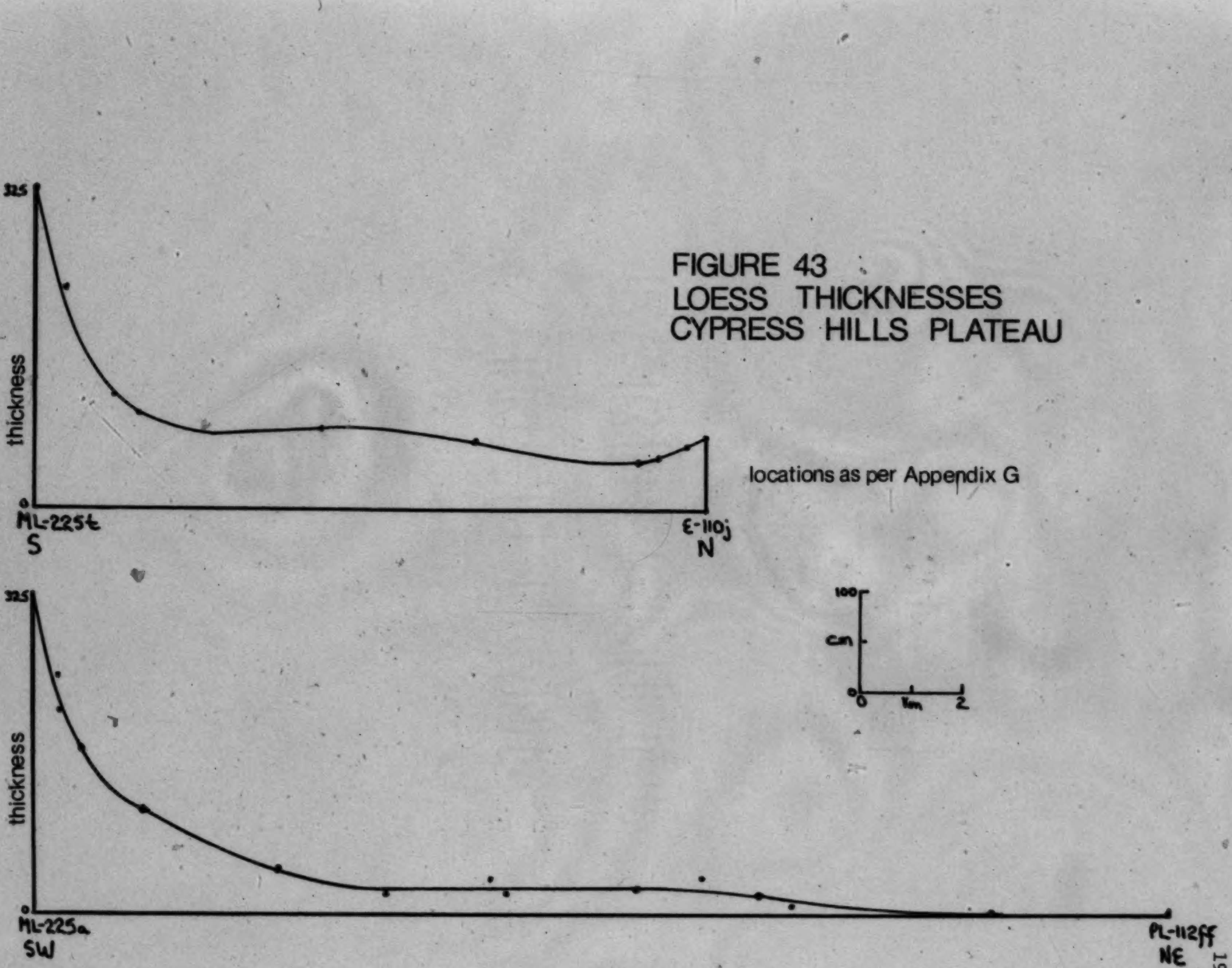


FIGURE 42
LOESS TEXTURE
VS. POSITION

FIGURE 43
LOESS THICKNESSES
CYPRESS HILLS PLATEAU



locations as per Appendix G

partially funnel the dominant westerly winds along the northern flank. Had strong northerly winds been present, the cliff-top deposits on the north escarpment would have undoubtably been the thickest of all because of the steep gradient and ready availability of suitable material.

An attempt was made to confirm the conclusions reached through study of the thicknesses of the loess deposits by examining the orientations of the grains contained within them. Oriented blocks of loess were obtained and stained with sodium cobaltinitrite applied as a fine spray. The orientations of the yellow-stained potassium feldspars exposed were then determined. The results indicate that the dominant trend in the central plateau area is 060°-240°. Values ranging between 155°-335° and 105°-285° were obtained from the exposures sampled (Figure 44, Table 28). Although no method of establishing the direction of movement was available, the results tended to confirm those obtained through direct measurements of sediment thicknesses. Significant non-systematic lateral variation was observed in all of the outcrops investigated. This is attributed to the effects of local turbulence induced by minor landform features.

Westgate (1964) suggested that the coarse-grained, poorly sorted sandy silt along the northern escarpment of the plateau was loess which had been extensively cryoturbated with the underlying Cypress Hills conglomerate. This conclusion was disputed by Jungerius (1966), who suggested that the deposit was colluvial in nature. After

FIGURE 44.

K-Feldspar Orientations in Loess, Cypress Hills Plateau.

The Figure illustrates typical orientation patterns at three sample localities on the Cypress Hills Plateau. Since no method of determining whether a particular clast is oriented towards the northeast or southwest, only the axes of transport directions are known. For clairty, only the southern hemispheres of the orientation diagrams are depicted; the northern hemispheres are mirror images of these.

Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale: 2.6 cm = 10 clasts

FIGURE 44

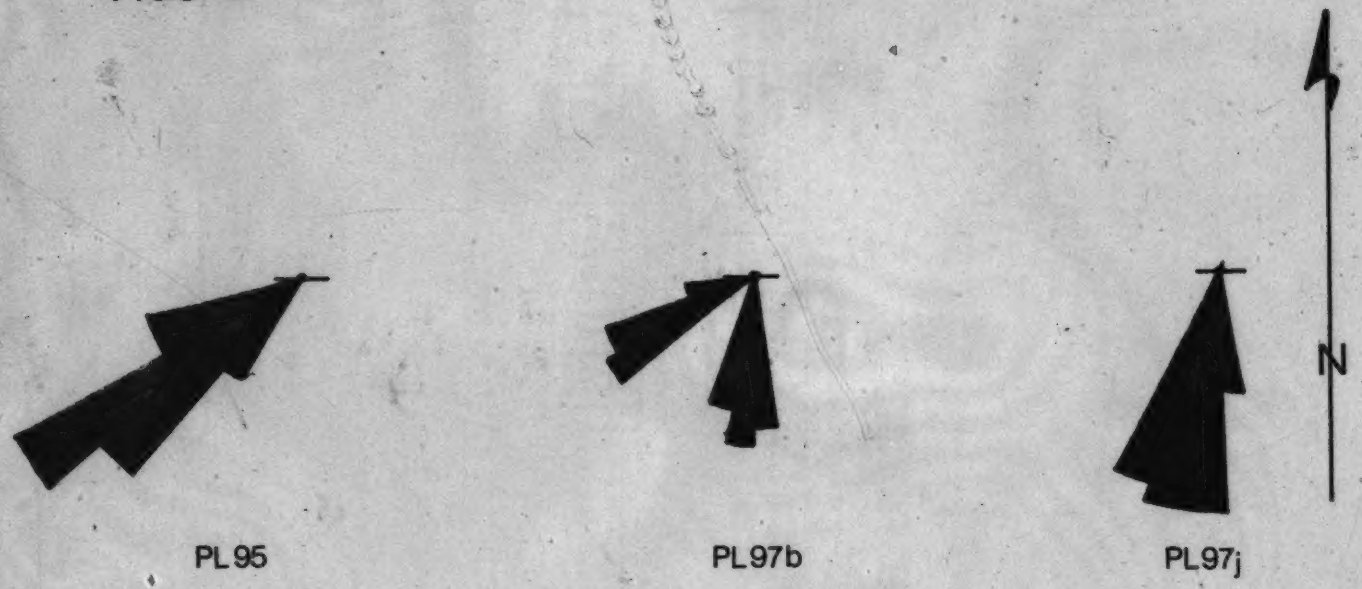


TABLE 28

Preferred Orientations of K-feldspar Particles in Loess, Cypress Hills Plateau

Preferred Orientation	Number of Localities	Percentage
155-165	1	1.5
165-175	2	2.9
175-185	4	5.9
185-195	0	0.0
195-205	3	4.4
205-215	2	2.9
215-225	6	8.8
225-235	10	14.7
235-245	14	20.6
245-255	12	17.6
255-265	8	11.8
265-275	4	5.9
275-285	2	2.9
TOTAL	68	100%

examination of the sediment, the author concurs with Jungerius in believing that it is composed of colluviated material derived from the Cypress Hills and Ravenscrag Formations. The texture of the sediment (Figure 45) does not suggest an aeolian origin, and the absence of the characteristic wedge-like form and the random orientations of the silt-sized potassium feldspar particles (Figure 46) also preclude this possibility. Westgate's (1964) suggestion that a dominant north wind deposited this material is contradicted by the absence of northerly-thickening sediment wedges, not only on the Cypress Hills Plateau but also along the southern sides of the Etzikom moraine and Seven Persons coulee. In addition, the presence of Mazama and Glacier Peak tephra originating from Oregon and Washington in the region is incompatible with the hypothesis of a dominant northerly wind.

Loess is also found as a thin blanket in the channels of coulees, and as wedges along west-facing bluffs and rises. The most significant deposits occur as a surface cap over the lacustrine sediments of the Walsh area. These deposits effectively mask the lacustrine shorelines, and are locally difficult to distinguish from lacustrine material. Silty sediments exposed at the surface in the Medicine Hat-Irvine area, thought to be lacustrine by Westgate (1964) and Christiansen (1979), are loess. The textural composition of this deposit corresponds with that of the Cypress Hills Plateau loess (Figure 47), and the mineralogical differences between the silt and the neighbouring and underlying sediments parallel the changes

FIGURE 45

TEXTURE,
CYPRESS HILLS
COLLUVIUM

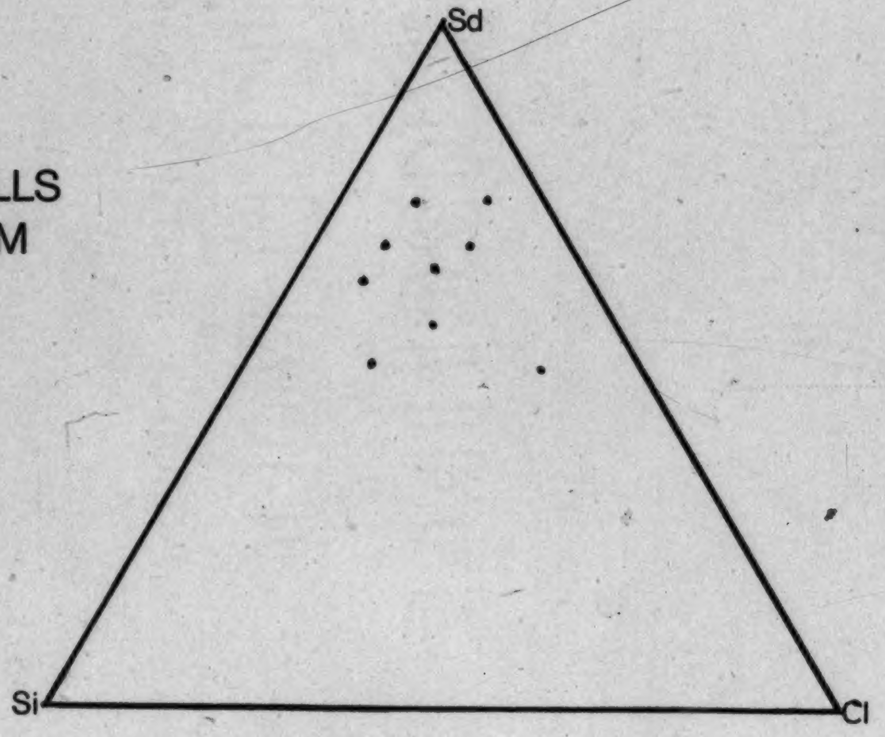


FIGURE 46.

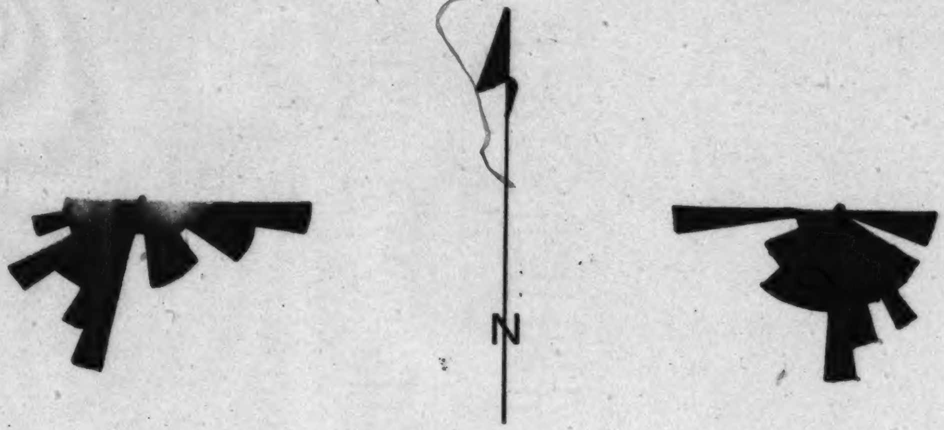
K-Feldspar Orientations in Colluvium, Base of Cypress Hills Escarpment.

The Figure illustrates the random orientations of silt-sized K-Feldspar particles in colluvium found at the base of the Cypress Hills Escarpment. Compare these random orientations with the strongly-oriented loess clasts (Figure 44).

Fifty clasts were measured at each locality. The readings are grouped in 10° intervals.

Scale: 2.6 cm = 5 clasts

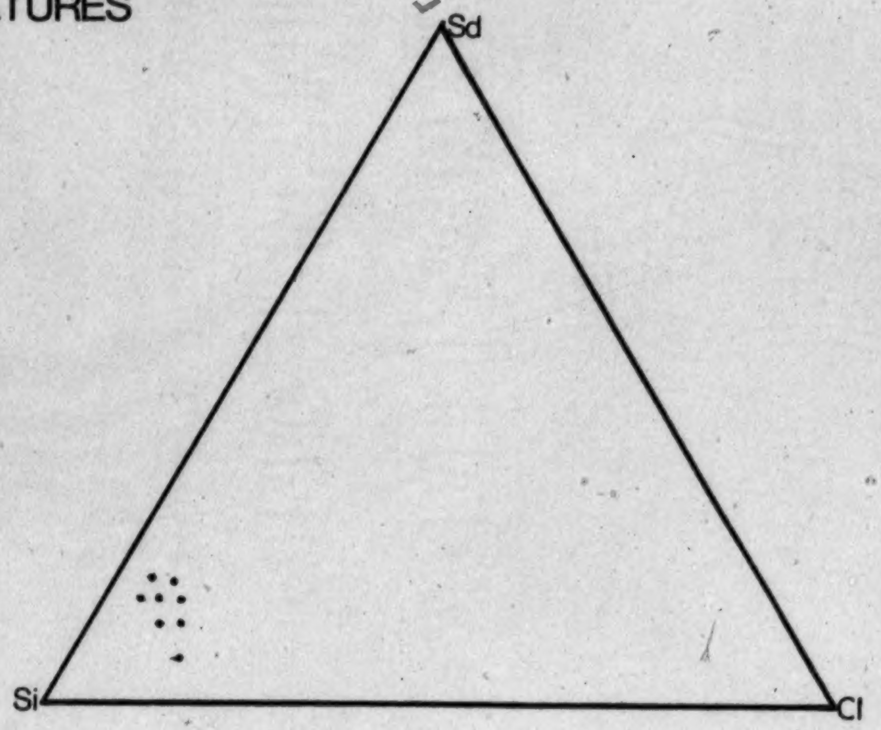
FIGURE 46



E2d

E2f

FIGURE 47
IRVINE LOESS TEXTURES



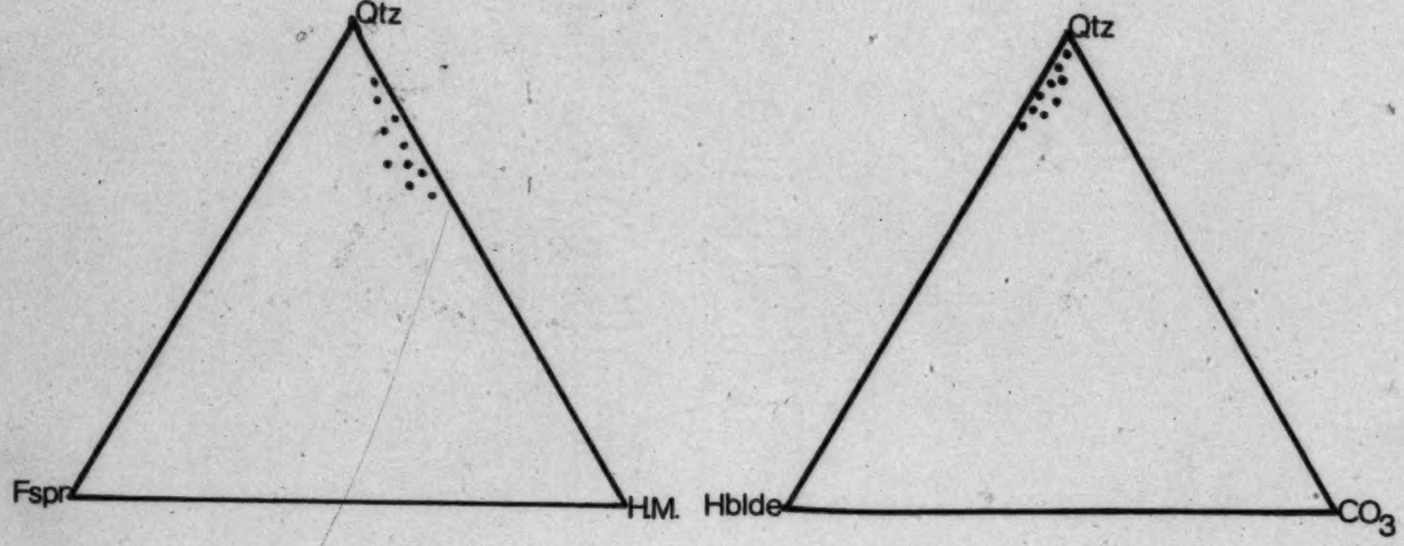
observed in the plateau escarpment area (Figure 48). The absence of nearshore lacustrine sediments in the area also suggests that the silt is of aeolian origin, a conclusion concurred with by David (1970) and Stalker (personal communication, 1979). No evidence supporting the existence of a Late Wisconsin lake in the Medicine Hat area has been recognized. Loess also obscures the morphology and fluvial sediments of the Many Island meltwater channel system, and the lacustrine sediments of Lake Wild Horse.

b) Sand Dunes

Aeolian sand is present as dunes in two areas of the study region. A small dune field exists in the Many Island Lake area, comprised of indistinct subparabolic dunes. These features are small and poorly defined, a condition apparently due to a limited duration of aeolian dominance rather than postformational alteration. Although the form of the dunes is not sufficiently well-defined to enable the direction of aeolian transport to be determined, indistinct cross-stratification suggests that it was from the southwest.

Another dune field is present adjacent to the northeastern edge of Pakowki Lake. The encroachment of these dunes over the lacustrine sediments deposited during the Ketchum and Orion II lake phases indicates that the dominant wind direction was from the west-southwest. A similar conclusion was reached through the study of cross-bedding in two rather poorly-developed sief dunes on the eastern side of the basin.

FIGURE 48
LOESS MINERALOGY, Irvine Area



The sediment of both dunal areas is predominantly fine-grained, quartz-rich sand depleted in carbonate relative to the surrounding areas. The heavy minerals present in the sand have been sorted and concentrated, and define the steep-angle cross-laminations of the dunes. Both dune fields were formed in post-glacial time, as indicated by their relationship to other sedimentary and geomorphological features. No pre-Holocene dunal sediment was identified in the study region.

c) Tephra

Numerous deposits of volcanic ejecta representing eruptions from Late Cretaceous to Holocene time were found in the study region. These sediments exhibited significnat differences in texture, mineralogy, detrital content, and degree of preservation of the glass shards. In order to facilitate discussion, the ashes of known age and those for which ages have been postulated through direct dating methods will be considered first. Those of uncertain age and vent affinity will then be discussed.

The Late Cretaceous and Early Tertiary ashes incorporated into the bedrock strata have been previously discussed. At several localities along Ross and Mackay Creeks and in the badlands east of Manyberries, these ashes have been eroded and reworked by fluvial and/or glaciofluvial action and redeposited as distinct pods or bands. These sediments, because they were deposited together with other material of the same grain size by flowing water, contain a high percentage of local non-volcanic material and are well-sorted. At locality MB-16c, a systematic decrease in the mean grain size with distance from the bedrock source in three distinct reworked ash lenses was noted, a pattern strongly suggesting fluvial sorting and deposition (Figure 49). The occurrence of ash horizons in the Bain area at elevations above the source bedrock layers (Table 29) indicates that glacial transport of the tephra is responsible for its current position. The presence of this material amidst medium-grained fluvial sands precludes the possibility of aeolian transport.

All of the reworked ashes can be identified as pre-Quaternary sediments on the bases of the degree of decomposition and superhydration of the shards according to the criteria of Steen-MacIntyre (1975), and the similarity between their phenocryst content and chemistry and those of the bedrock ashes (Appendices B and C). Reworked tephra from several locations was observed to contain distinctive components derived from two or more bedrock sources, again indicating the probability of glacial transport and mixing.

The oldest Quaternary ash known in southeastern Alberta is the Galt Island tephra, discovered at the base of the Galt Island section on the South Saskatchewan River 10 km westof Medicine Hat by Stalker in 1974. Fission-track dating of the zircon phenocrysts indicates that the ash is 430 thousand years old (Stalker, personal communication, 1979). The source volcano of the tephra is unknown.

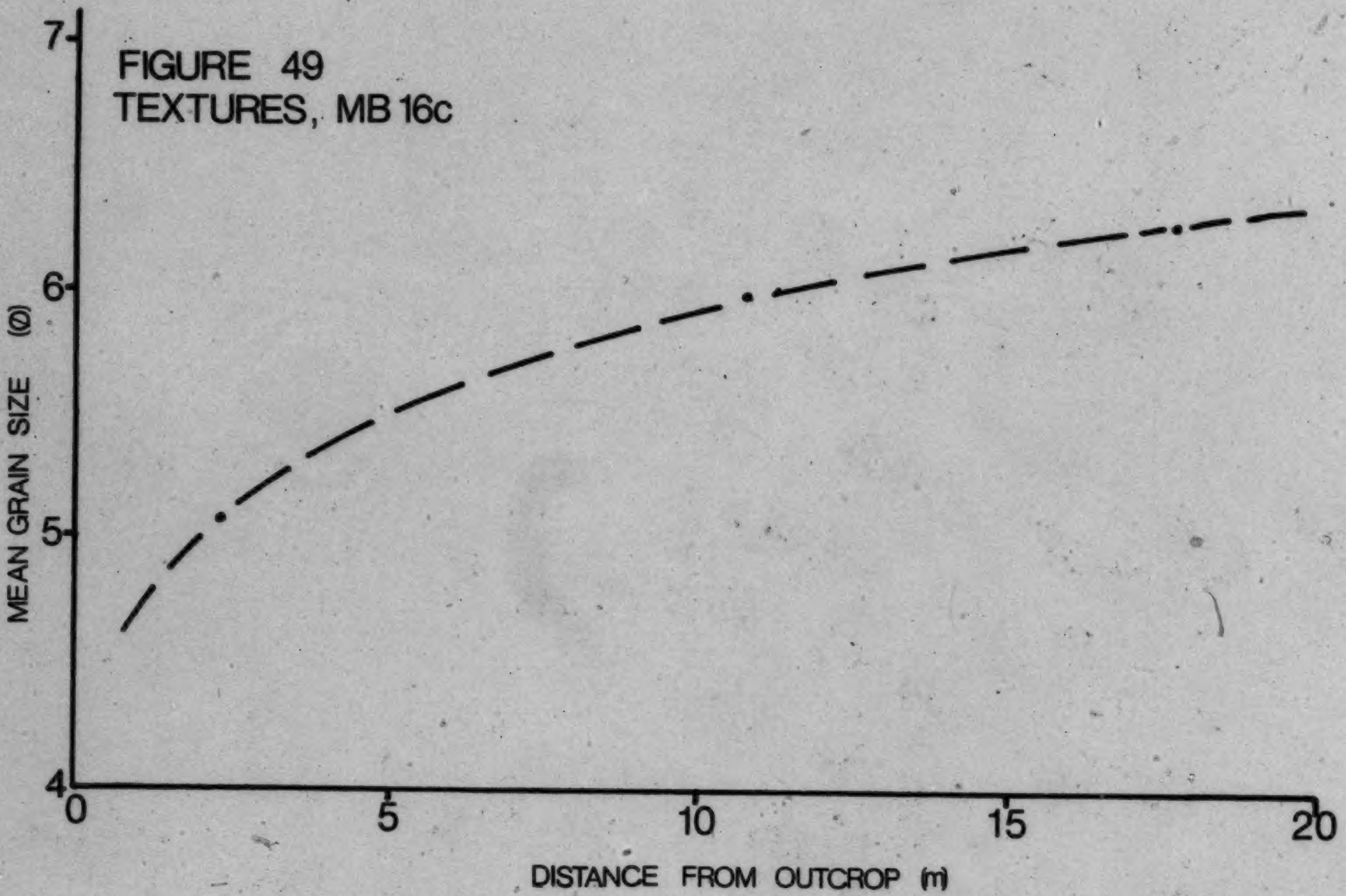


FIGURE 49
TEXTURES, MB 16c

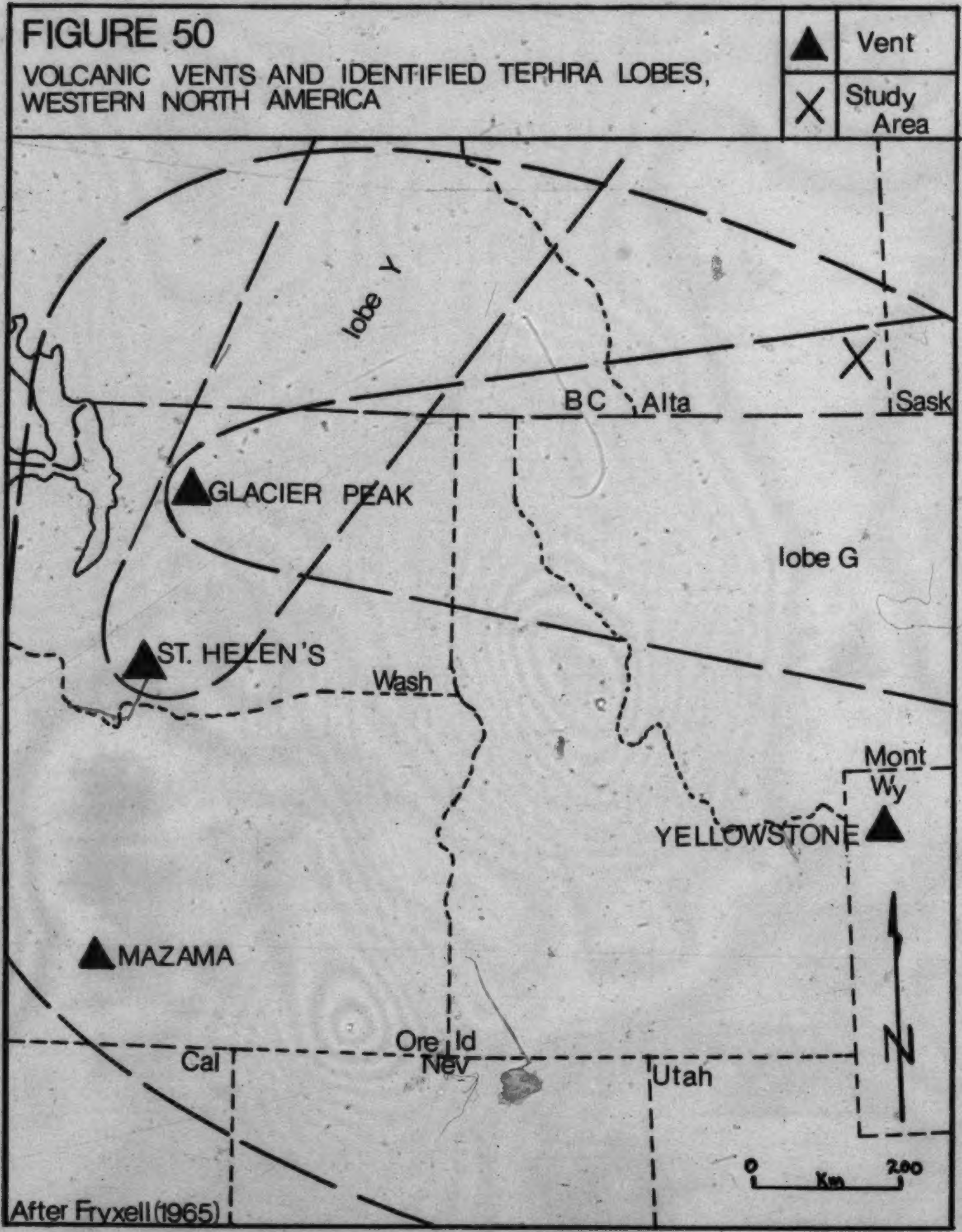
TABLE 29

Redeposited Tephra Strata in Relation to Bedrock Tephra, Bain-Manyberries area.

Redeposited Tephra		Bedrock Tephra Source			Nearest Bedrock Outcrop		
LOCATION	ELEVATION	FORMATION	LOCATION	ELEVATION	FORMATION	LOCATION	ELEVATION
MB-15m	1112 m	Oldman	MB-15a	1020 m	Bearpaw	MB-15n	1097 m
B-183a	941 m	Oldman	B-183a	929 m	Oldman	B-183a	929 m
MB-15i	1120 m	Bearpaw	MB-15g	1097 m	Bearpaw	MB-15g	1078 m
MB-15p	1110 m	Bearpaw	MB-15d	1084 m	Bearpaw	MB-15d	1084 m
MB-15g	1106 m	Bearpaw	MB-15d	1084 m	Bearpaw	MB-15d	1084 m
B-183b	954 m	Bearpaw	B-183b	950 m	Bearpaw	B-183b	950 m
B-182	991 m	Unknown	-	-	Bearpaw	B-183b	950 m

FIGURE 50

VOLCANIC VENTS AND IDENTIFIED TEPHRA LOBES, WESTERN NORTH AMERICA


Vent
Study Area
lobe Y
BC
Alta
Sask
GLACIER PEAK
lobe G
ST. HELEN'S
Wash
Mont
Wy
YELLOWSTONE
MAZAMA
Ore
Id
Cal
Nev
Utah
0
Km
200

After Fryxell (1965)

The ash was not found at the Galt Island locality by the author, and it appears that the pocket investigated by Stalker has been completely eroded and dispersed.

The oldest ash in the study region which has been assigned a definite date is the Manyberries tephra, located in a bluff exposure 0.4 km south of Manyberries (locality MB-11). This section has been described previously by Westgate (1964, 1968). The ash is exposed as a continuous, irregularly undulating band 1.5-2 cm thick. Minor discontinuous ash layers subparallel to the main unit are exposed in the underlying sediments. The principal band is overlain by 7.5 m of interbedded silts and clays with irregular coarse sand lenses, deposited during the Manyberries I lacustrine event, and in turn overlies 0.9 m of similar sediments. The lacustrine unit has been previously described in detail. This sediment is underlain unconformably by a gneiss-rich glacial outwash gravel, which grades laterally and vertically into pebbly ablation till deposited during glacial phase B.

All of the tephra strata are cut irregularly by minor normal faults and joints. These faults are not discernable in the surrounding structureless lacustrine clay, and are absent from the varved sediments present at higher elevations in the section. At several locations in the section, the major tephra unit is contorted into V-shaped depressions. The presence of coarse sand in the depressions above the ash and their form and alignment suggest that they were formed by iceberg gouging and ice-shove processes, as were

FIGURE 51.

Quaternary Ashes, Study Region.

The Figure indicates the position of deposits of Quaternary tephra in the study region.

Legend

●	Mazama
X	Other Tephra
D	Dunmore
E	Elkwater
I	Irvine
M	Manyberries
MH	Medicine Hat

FIGURE 51 QUATERNARY ASHES, STUDY REGION

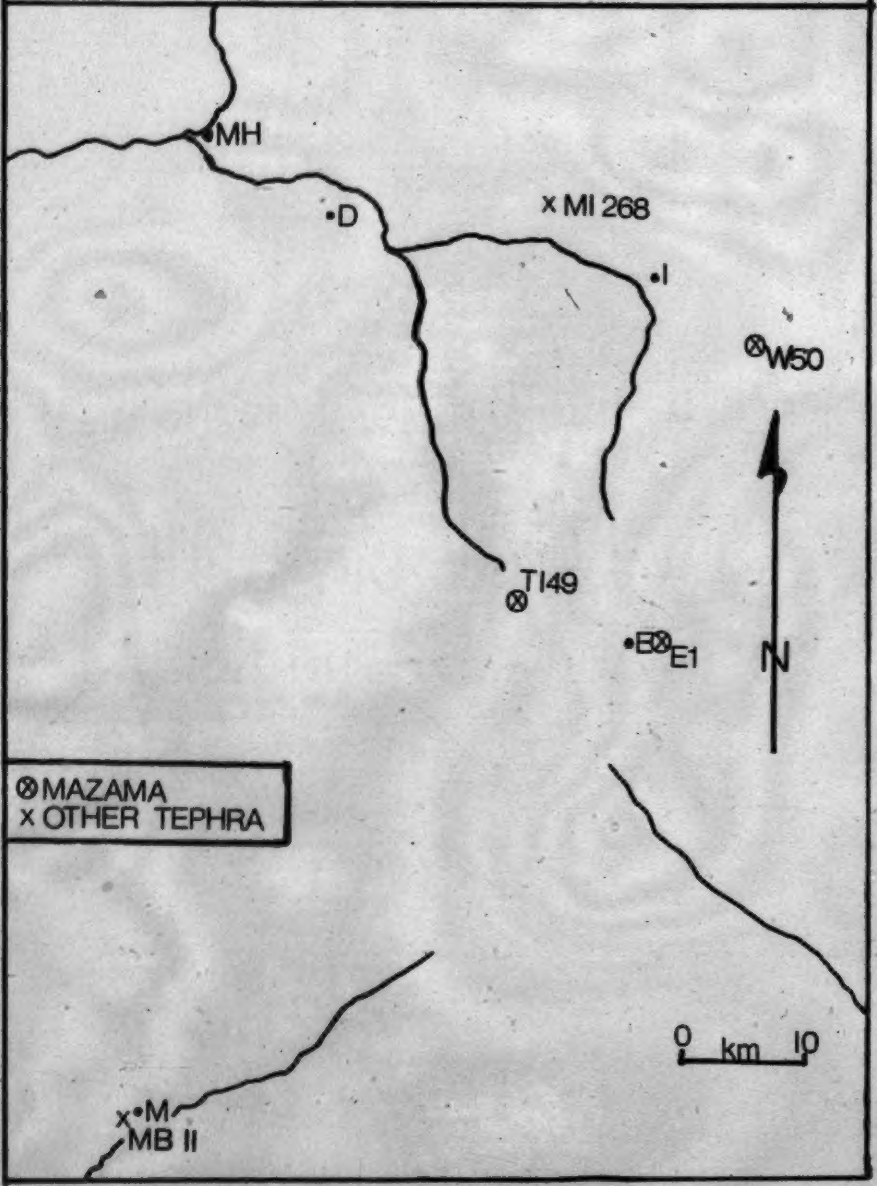

MH
D
x MI 268
I
⊗W50
T149
E⊗E1
N
⊗MAZAMA
x OTHER TEPHRA
0 km 10
x M
MB II

PLATE 12. Reworked Bentonite contained in Ravenscrag Formation, Locality ML-5. The bentonite was derived from a number of horizons in the Bearpaw, Whitemud, and Battle Formations. See text for discussion, and Appendices B and C for analyses of the bentonite.

PLATE 13. Glacier Peak G ash, Manyberries, Locality MB-11. This ash is exposed as an irregular, contorted stratum 1 cm thick.

COLOURED PICTURE

the normal faults and joints.

The tephra units are composed almost exclusively of medium silt. The absence of apatite and chinopyroxene from the phenocryst fraction is noteworthy, as are the relatively high concentrations of ilmenite and ulvospinel. Chemically, the low sodium: potassium ratio and iron content serve to characterise this ash. These characteristics are summarized in Table 30.

On the basis of the chemical content, Smith and Westgate (1969) characterised the tephra as a Glacier Peak ash, originating from that volcano in western Washington State. Porter (1978) recognized nine separate eruptions of the Glacier Peak volcano, and correlated the Manyberries deposit to the earliest of these, event G. This correlation was subsequently confirmed by Westgate and Evans (1978).

An exposure of Glacier Peak G tephra at Diversion Lake, Montana, has been radiocarbon-dated at 12750±350 BP (W-1644; Ives et al, 1967). The date was obtained from terrestrial gastropods which were buried along with lenses and pods of the ash in a 21 cm thick unit of silt sandwiched between alluvial fan gravels (Mudge, 1967). Evidently, some reworking of the ash has occurred. The only other locality in Montana where Glacier Peak G tephra has been identified has an equally unclear stratigraphic record. Silts containing the ash at New Rockport, Montana, which were identified as proglacial lacustrine sediments by Lemke et al (1975) have subsequently been identified

TABLE 30

Comparison of Manyberries Tephra (MB-11) and Glacier Peak G Tephra

	Manyberries	Glacier Peak G
% Fe_2O_3	1.18	1.18*'; 1.16"
% Na_2O	3.94	3.92*
% K_2O	3.37	3.33*
% Cl	0.16	0.16*
Refractive Indices		
Glass Shards	1.500-503	1.501-506*
Hornblende°	1.645	1.649"
Orthopyroxene°	1.694	1.695"
Clinopyroxene	-----	-----
Other Minerals		
	Biotite	Biotite"
	Garnet (Grossularite)	Garnet" (Grossularite)
	Ilmenite	Ilmenite"
	Magnetite	Magnetite"
	Ulvospinel	Ulvospinel"
Silt Content	93%	93%**

*After Westgate and Evans (1978)
**After Westgate (1964)
'Recalculated from % FeO
"Measured by author from Diversion Lake, Montana, locality (described in Lemke *et al*, 1975)
°Refractive indices are n_x

as alluvial (Fullerton, United States Geological Survey, personal communication, 1979), or colluvial (Stalker, personal communication, 1979). No material suitable for dating is present at this site.

If the Glacier Peak G tephra at Diversion Lake has been subjected to downslope movement after deposition, it could conceivably be older than 12750 BP. Since the fan deposits overlie Pinedale glacial outwash, they must be younger than the Pinedale glaciation. This event is believed by Richmond (1965) to have occurred during the Late Wisconsin. Thus, the ash must be between approximately 20000 and 12750 years old. If the Pinedale glaciation is in fact older than the Late Wisconsin, a supposition which is in accordance with the data collected regarding apparently correlative tills in the western Cypress Hills region, then the maximum age of the ash is also increased. The presence of the Glacier Peak B (Chiwawa) ash above the G tephra in the Northern Cascade range (Porter, 1978) confirms the estimate of the minimum age, since it has been dated at 12000±310 BP (WSU-155; Fryxell, 1965).

The Manyberries I lacustrine event, sediments of which contain the G tephra at Manyberries, has already been demonstrated to be a proglacial lake. Since the lake's northern shore was formed by the glacial front, the age of the tephra would be identical to the oldest possible date of ice retreat from the Etzikom moraine position. Thus, if the Diversion Lake date is accepted unreservedly, the date of the termination of the Phase C glacial event and the commencement of the general ice retreat was 12750 BP, or some time thereafter. If the age of the Diversion Lake tephra is considered to be 20000 BP, this date then represents the earliest possible retreat from the Phase C maximum. The assumption of an early retreat agrees more closely with the stratigraphic data collected in other parts of southern Alberta (Stalker, 1977; Jackson, 1979; Stalker, 1980 in preparation), and southern Saskatchewan (Christiansen, 1979). Based on the data collected in these areas, the commencement of the retreat from the Phase C glacial maximum appears to have occurred c. 17000 BP, a conclusion which agrees with data obtained from the study region. This date lies well within the probable range for the age of the Glacier Peak G tephra.

The youngest and best-documented tephra layer in the region is the Mazama ash. Occurrences of this ash within the area have been documented at Elkwater (Gryba, 1975; Westgate, personal communication, 1980) and Mackay Creek (Westgate, 1972). The tephra, contained in irregular lenses and pods, is interbedded with alluvial and colluvial sediments at both localities. Additional occurrences of Mazama tephra in colluvium were noted by the author in the Elkwater area (E-1b), and along Gros Ventre Creek (T-149a).

The ash can readily be recognized by its high iron and sodium content, and by the presence of apatite and clinopyroxene (Smith and Westgate, 1969, Lemke *et al*, 1975). The glass shards are

PLATE 14. Reworked Mazama ash, Locality T-149. The tephra is contained in irregular pockets throughout the fluvial sand deposit.

COLOURED PICTURE

characterized by a bimodal refractive index and silky habit. Texturally, the sediment is almost entirely fine silt. These characteristics are summarized in Table 31. The content of non-volcanic detritus is high, due to the colluvial reworking that the tephra has undergone at all the sample locations.

The age of the Mazama eruption has been established at 6600 BP (Fryxell, 1965). The numerous occurrences of Mazama tephra throughout southern Alberta (Smith and Westgate, 1969; David, 1970; Waters, 1979) have enabled its relationship to the postglacial sequence of events and the development of soils to be determined.

The origin and age of the Irvine ash (Westgate and Evans, 1978) is uncertain. The tephra is exposed in a bluff adjacent to a meltwater channel 9 km north of Irvine (MI-268). Westgate and Evans (1978) describe the sediments enclosing the tephra as supraglacial lacustrine silts which form the core of a crevasse filling in the Walsh (Oldman) drift. After a careful examination of these sediments, the author believes that the silt unit is a loess. The textural and mineralogical composition correspond to the loess deposits of the Walsh and Medicine Hat areas (Figures 52 and 53). The absence of pelecypods and diatoms from the deposits and the presence of terrestrial mammal bones also suggest that the silts are not of lacustrine origin. Furthermore, the sediment described as till by Westgate and Evans (1978) appears to be colluvium. Although it is often difficult to distinguish between ablation till and colluviated material, the

TABLE 31

Mazama Ash Characteristics

	E-1	E-1b	W-50	T-149a	Westgate and Smith, 1969	Lemke *et al*, 1975
Fe_2O_3	2.15%	2.12%	2.14%	2.17%	2.23±0.06%*	2.07%*
Na_2O	5.20	5.19	5.11	5.21	5.23±0.16	4.60
K_2O	2.61	2.59	2.62	2.58	2.67±0.04	2.77
Cl	0.18	0.17	0.17	0.18	0.18±0.02	n.d.**
Refractive Indices						
Shards	1.499-509	1.499-509	1.500-9	1.499-509	n.d.	1.499-511
Hornblende***	1.658	1.659	1.661	1.660	n.d.	1.658-665
Orthopyroxene***	1.689	1.690	1.691	1.690	n.d.	1.688-692
Clinopyroxene***	1.686	1.686	1.687	1.687	n.d.	1.686-689
Silt Content	95%	99%	96%	90%	n.d.	n.d.
Other Minerals		Apatite Biotite Garnet Ilmenite Magnetite Zircon				Apatite Biotite Garnet Ilmenite Magnetite Zircon

* Recalculated from FeO

** not determined

*** modal value determined by author for n_x

FIGURE 52
TEXTURE, MI 268

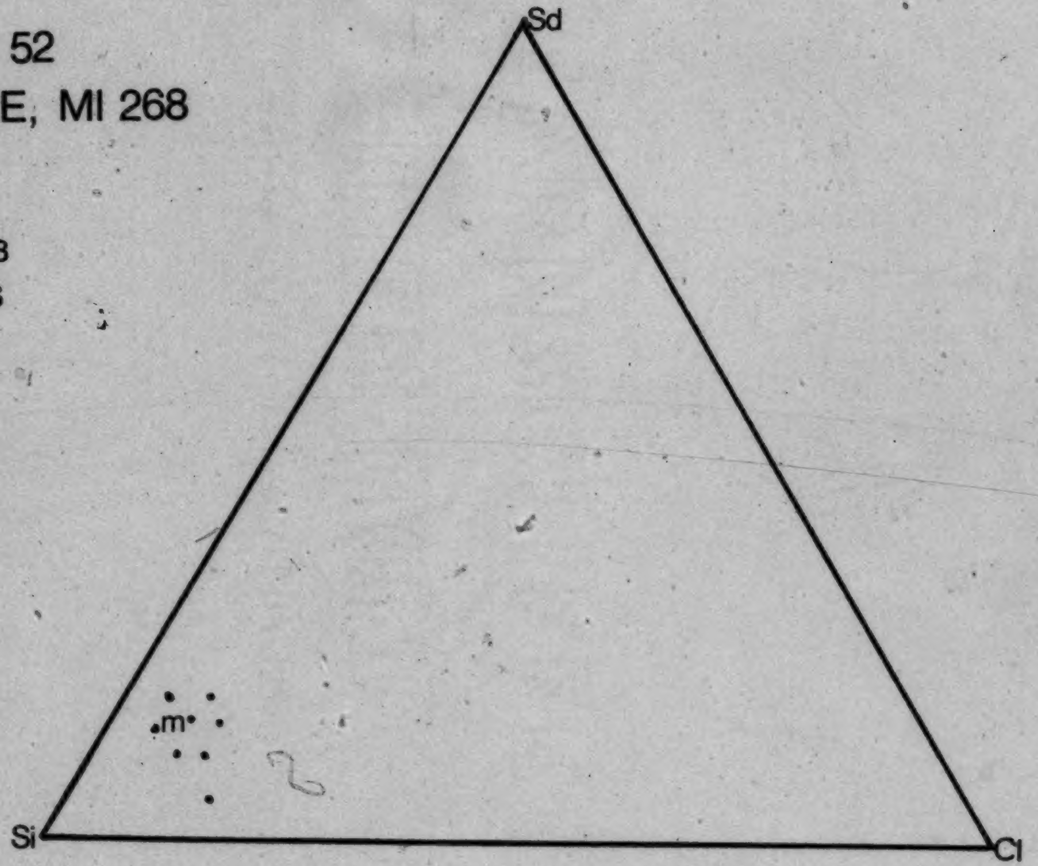


FIGURE 53
MINERALOGY, MI 268

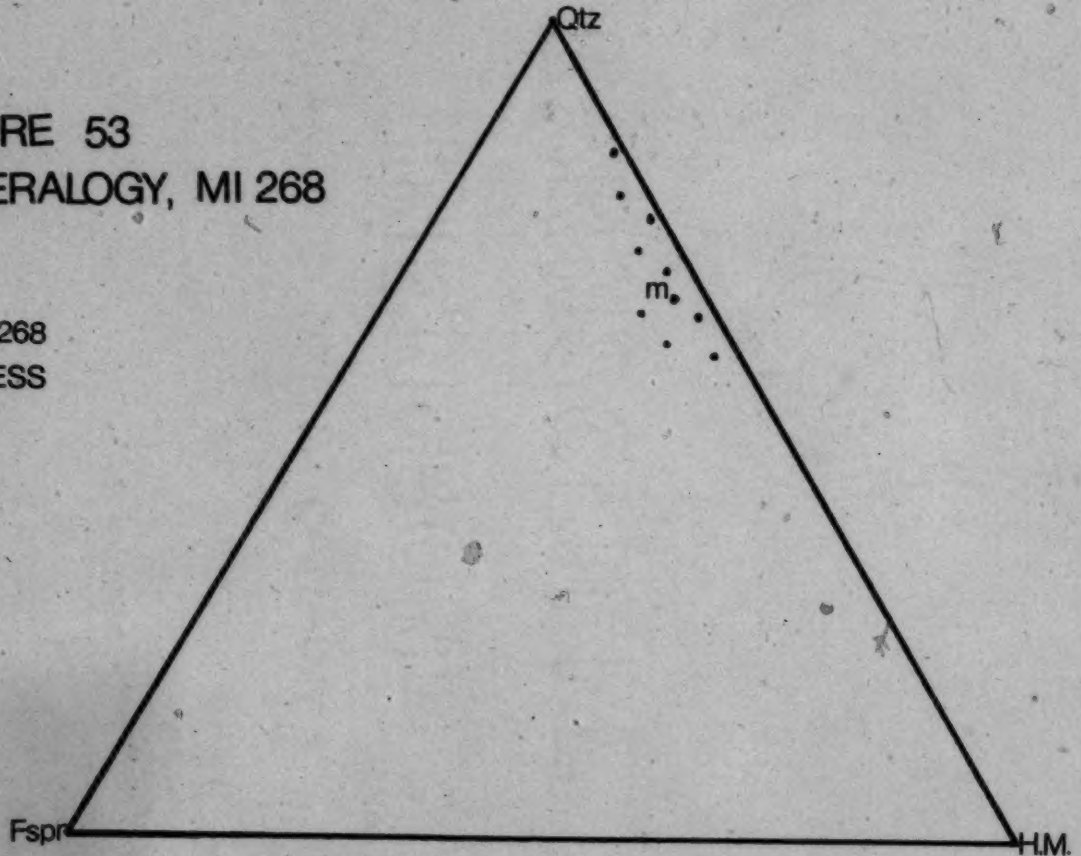


PLATE 15a. Irvine Ash, Locality MI-268, as seen in 1972. The tephra appears as a discrete, continuous stratum across the entire outcrop. (Photograph courtesy of N.W. Rutter, Univ. of Alberta)

PLATE 15b. Irvine Ash, Locality MI-268, as seen in 1979. The tephra is exposed only as a series of irregular, discontinuous pods amidst colluviated material. See text for further discussion.

COLOURED PICTURE

presence of mammalian bone fragments similar to those extracted from the adjacent loess suggests a masswasting origin for this deposit.

The ash is characterised by low iron and sodium contents, relatively high concentrations of ilmenite and ulvospinel, and an absence of apatite and clinopyroxene (Table 32). Based on these characteristics, it is assumed to be a Glacier Peak ash (Westgate and Evans, 1978). However, its characteristics do not correspond exactly to any of the nine Glacier Peak strata recognized by Porter (1978).

The degree of weathering and hydration of the shards, as determined using the technique of Steen-MacIntyre (1975), suggest that this tephra unit is older than the G layer exposed at Manyberries. The absence of a pre-G ash bed in the North Cascade range (Porter, 1978) may indicate that the Irvine bed was produced by a different volcano (Fullerton, personal communication, 1979).

Westgate and Evans (1978) believed that the tephra was a Late Wisconsin deposit, because of their interpretation of the environment in which the enclosing silts were deposited. Consequently, they rejected the radiocarbon date of 7965±130 BP (I-8486) obtained from bones 40 cm above and below the tephra. The author believes that this radiocarbon date accurately reflects the approximate time of deposition of the loess. Consequently, the Irvine tephra was either produced by a later eruption of the Glacier Peak volcano, or it was produced by an eruption of an unknown British Columbia or Cascades

TABLE 32

Irvine Ash Characteristics, Locality Mi-268

	MI-268	Westgate and Evans, 1978
Fe_2O_3	1.02	1.04*
Na_2O	3.92	3.94
K_2O	3.41	3.40
Cl	0.15	0.15
Refractive Indices		
Shards	1.497-506	1.496-505
Hornblende**	1.643	n.d.***
Orthopyroxene**	1.695	n.d.
Clinopyroxene	none	-----
Other Minerals		
	Biotite Garnet Ilmenite Magnetite Ulvospinel	Biotite Garnet Ilmenite Magnetite Ulvospinel

* Recalculated from FeO
** Modal Value for n_x
*** Not determined

vent, or it was produced by the aeolian reworking of a previously-deposited tephra. At present, no basis for choosing from amongst these possibilities exists. The absence of Glacier Peak tephra younger than 12000 BP in the Cascades militates against the first possibility, while the absence of correlative tephra in other localities seems to preclude the third at present. The second possibility is therefore the most likely, but the close similarity between the ashes produced by such a vent and the Glacier Peak volcano is quite peculiar in the light of the observed differences between the tephra produced by the known vents.

Three of the cores obtained from the Elkwater site, DjOn-26, contain ash strata interbedded with alluvial silt units. A total of six tephra layers were noted; each of which is described chemically in Appendix B and mineralogically in Appendix C. Each layer contained a diverse assemblage of minerals, shard types, and non-volcanic material. In no instance could a definite source be determined. Most of the shards present were severely altered and weathered, suggesting that much of the tephra was reworked from the surrounding bedrock strata. The presence of minerals such as cummingtonite and chevkinite, which are not present in any of the Quaternary ashes of the region, also suggests derivation from the bedrock. The extreme degree of weathering displayed by the shards precludes the possibility that these ashes are Mid-Quaternary in age, and their chemistry and composition do not correspond to the two pre-Wisconsin

Quaternary ashes known from the Canadian Prairies, the Wascana Creek tephra (Westgate _et al_, 1977), and the Galt Island tephra discussed above.

The stratigraphic position of the ashes with respect to the majority of the source bedrock strata suggests that the tephra was glacially eroded, transported to the site during the Phase A glaciation, and subsequently redeposited by fluvial action. The high proportion of detrital material observed in the strata supports this conclusion. The presence of coarse sand incorporated into the units indicates that aeolian action could not have transported the material. The horizons appear to be a complex mixture of glacial debris which was sorted subsequent to its initial deposition by glacial meltwater and fluvial activity. During this sorting process, the tephra was concentrated in distinct lenses, due to its unimodal silt texture. Other non-volcanic material of the same grain size was also incorporated into the pods in the same manner.

The strata formed by this process thus contain ash particles from a variety of sources. As no method exists for ascertaining which of these sources was responsible for the most recent matter, or indeed for difinitively identifying the sources, the age of these tephra units cannot be determined independently of the inferred age of the Phase A glaciation.

ISOSTATIC RECOVERY

Isostatic recovery is defined as the rise of the earth's crust towards its equilibrium position, controlled by a pressure differential. In glaciated regions, the pressure differential is created by the application and removal of increments of glacial ice; hence, the dominant process in these areas is glacio-isostatic recovery. After an initial period of doubt in North America (eg. Tyrrell, 1896), glacio-isostatic recovery of the landscape has become accepted as a mechanism for explaining the presence of tilted lake levels and rising regions.

Numerous theories accounting for the mechanism and duration of isostatic recovery have been developed, based chiefly on data gleaned from the Great Lakes and Arctic Canada. Most of these theories have assumed that the earth's crust combines elements of brittle, plastic, and elastic behaviour, resulting in a combination of pressure-release fracturing, subcrustal and intracrustal mass transfer, and simple bending upon deglaciation. The relative degree of importance attached to each of these mechanisms for crustal elevation varies from theory to theory.

The most commonly used theory explaining isostatic recovery was proposed by Crittenden (1963). Working with the raised beaches of pluvial Lake Bonneville in central Utah, he devised an emprical relation between the time since deglaciation and the proportion of the total deformation which has been recovered:

(1) $r = 1 - e^{-t/Tr}$

where r is the proportion of total deformation recovered; t, the time since deglaciation; and Tr a constant defined as the relaxation time. When t=Tr, the proportion of recovery remaining is e^{-1} or 36.8%. The relaxation time is an empirically-derived constant, but numerous determinations of relaxation times (eg. Crittenden, 1963; Johnston, 1978; Catto et al, 1980, in press) have all produced values ranging between 3,200 and 3,700 years. Since the relaxation time is a function of crustal rigidity, the consistency shown by these values is not surprising.

To employ the Crittenden formula, the relaxation time of the area must be known, as well as the approximate position of the ice front. The relaxation time can sometimes be derived by amassing enough field data to suggest an empirical value. More commonly, curves employing different values of relaxation time are plotted and then compared with the results obtained in the field. The latter course was followed in this study. Although additional evidence has come to light suggesting that recovery processes are not the simple procedure which Crittenden (1963) envisaged, this theory remains an acceptable first approximation of isostatic recovery.

Walcott (1972) has devised a mechanism for isostatic recovery based on the simultaneous occurrence of two recovery modes: a short-term parameter, due to the simple elastic recovery of the crust upon deglaciation; and a long-term factor, due to subcrustal mass transfer from the surrounding areas to the recently deglaciated region. Walcott's equation, supported by an elaborate geophysical argument, states that:

(2) $\text{Uplift remaining} = 150\ e^{-t/1000} + 450\ e^{-t/50,000}$

where t is the time since deglaciation, and the uplift is calculated in feet. The constants 1,000 and 50,000 are derived from geophysical arguments dealing with crustal rigidity (viscosity) and subcrustal mass transfer processes, and represent the time factors controlling these processes (measured in years). The constants 150 and 450 are derived from Walcott's assumption of 600 feet (183 m) of total uplift, and a 3:1 ratio of uplift due to subcrustal mass transfer against uplift due to elastic unloading of the crust.

While the basic geophysical arguments regarding bimodal crustal recovery are accepted by the author, the specific values for the constants in equation (2) are questioned. Catto _et al_ (1980, in press) derived a related equation for the Ottawa Valley region:

(3) $\text{Uplift Remaining} = (x/2)\ e^{-t/1500} + (x/2)\ e^{-t/5000}$

assuming a total uplift of x m. Theoretically, this equation should be applicable to any area for which the total uplift can be measured or estimated.

If it is assumed that the earth's crust is deformed in an elastic manner to its maximum theoretical extent by the initial application of the ice load, and that no subcrustal mass transfer occurs prior to deglaciation, then the maximum deformation is given by:

(4) $$D = \frac{p\ ice}{p\ crust} \times \text{thickness of ice}$$

Thus, if an estimate of ice thickness can be made, an approximation of the total deformation can be determined.

Although this equation represents a considerable simplification of the actual processes by which isostatic recovery takes place, it appears to provide an acceptable estimate of the total amount of rebound which occurs at glaciated localities at least 50 km from the ice front. Table 33 provides a comparison between actual rebound values and those produced through application of equation (4) for a number of localities in the Ottawa Valley region. Without an accurate idea of the chronological progress of deglaciation, and without sufficient data to construct regional isobases, application of a more sophisticated rebound model is impossible.

The position of erratics along the northern slope of the Cypress Hills Plateau were used to estimate the minimum thickness of the Phase A and B ice sheets. These figures were then combined with the surface profiles of present-day glaciers to produce estimates of ice thicknesses of locations removed from the glacial maxima. Stalker (1965), using this procedure, obtained the following estimates of ice thickness:

	Phase A	Phase B
Maple Creek	671 m	610 m
Medicine Hat	853 m	716 m
Milk River	351 m	259 m
Shaunavon	427 m	335 m

TABLE 33

Estimates of Isostatic Depression, Ottawa Valley Area

Location	Estimated Thickness of Glacial Ice	Estimated Rebound (Equation 4)	Rebound Measured
Ottawa, Ont.	652 m	236 m	239 m
Cantley, Que.	657 m	237 m	248 m
Kingsmere, Que.	665 m	240 m	246 m
Clayton, Ont.	682 m	246 m	240 m
Renfrew, Ont.	720 m	260 m	243 m
Shawville, Que.	765 m	276 m	264 m
Westmeath, Ont.	765 m	276 m	266 m

Assuming that the crust is dominantly sialic, and has an approximate modal porpsity of 5%, the specific gravity of the strata is approximately 2.52. Thus, since the specific gravity of glacial ice is 0.91, the following estimates of maximum crustal depression during Phase A were obtained:

Maple Creek	268 m
Medicine Hat	341 m
Milk River	141 m
Shaunavon	171 m

For Phase B, the possiblity that residual depression caused by Phase A remained must be considered. Consequently, the crustal depression existing immediately after Phase B lies somewhere between the figures for Phase A-induced depression, and the following figures for depression caused by Phase B:

Maple Creek	244 m
Medicine Hat	287 m
Milk River	104 m
Shaunavon	134 m

Since the Phase C glaciation did not reach the Cypress Hills, a different method of estimating the ice thickness must be used. In the vicinity of Irvine, the Phase C moraine rises 75 m above the base of the Irvine-Walsh meltwater channel. Thus, it can be assumed that the ice at this locality was approximately 75 m thick, after allowing for the surface profile of the ice sheet near the moraine and postglacial downcutting along the meltwater channel. Applying equation (4), the depression due to the Phase C glaciation in this area was 29 m. Similar values were obtained from points along the Phase C moraine in the Nemiscam, Etzikom, and Bullshead Creek areas.

Isostatic recovery begins prior to the complete deglaciation of an area, because the ice load is removed in increments rather than as a single unit. This is especially true in areas where ablation takes place primarily by vertical wasting, such as southern Alberta. The difficulties caused by this pattern of ablation can be avoided if it is assumed that recovery begins shortly after the ice sheet commences recession from its maximum position.

Application of equation (3) to the data obtained by Stalker (1965) indicates that isostatic recovery from the Phase A glacial load progressed rapidly, and was essentially complete _c_.40,000 years after retreat from the glacial maximum began. Thus, no depression would remain after a post-A interglacial period.

The data relating to the Phase B event are of greater interest, because the conclusions generated can be checked against landforms which are currently exposed. Insertion of the value of 287 m obtained for Medicine Hat into equation (3) reveals that total recovery requires approximately 32,000 years. After 5,000 years, 58 m of depression remain, while at 10,000 years, 20 m exists. If the Phase B maximum occurred _c._ 20,000 BP, features formed during the early Holocene would be tilted today, due to isostatic depression at the time of their formation. However, river terraces formed in the Medicine Hat and Irvine areas are not tilted. Neither are fluvial sediments found at these locations. No tilting of Early Holocene fluvial deposits was reported from the Red Deer area by Stalker (1960) or from the Edmonton area by Westgate (1969). No evidence of isostatic rebound of the terraces of the Red Deer or North Saskatchewan Rivers has been observed by the author. The only conclusion possible from these observations is that rebound had ceased by the time of the formation of these features. Thus, the Phase B glaciation maximum must significantly pre-date the Late Wisconsin stadial, c. 20,000 BP.

Isostatic depression produced by the Phase B glaciation was responsible for the formation of the periglacial Lake Wild Horse series, in the Southeastern corner of the study region. Since no bedrock or sediment barrier capable of impounding the lake exists, the only possible mode of formation of the lake basin was isostatic depression of the area. The difference in elevation between the southernmost sediments of the lake (in Montana) and the northernmost lacustrine material, 50 m, gives an estimate of the maximum amount of rebound since deglaciation. Comparison of the values computed for total rebound for Shaunavon and Milk River and this value indicates that between 50% and 60% of the total isostatic recovery occurred prior to deglaciation. Isostatic recovery of the region is estimated to have commenced approximately 2700 years before deglaciation.

Although no trace of isostatic imbalance created by Phase B can be found north of the Etzikom moraine, all of the terraces south of this moraine are tilted towards the northwest. Measurement of the degree of tilt of the fluvial terraces and sediments exposed along Canal Creek indicates that the total rebound in this area since deglaciation was approximately 35 m (Table 34), an estimate in accordance with the value generated from the application of equation (3). The recovery rate also agrees with an estimate produced from equation (1) (Crittenden, 1963) using a value of 3500 years for the relaxation time. The general concurrence of values produced from all three methods indicates that the fundamental assumptions made in the generation of equations (1) and (3) are sound.

Isostatic recovery following Phase C was much more rapid than those which followed Phases A and B, because the amount of depression was much less. If it is assumed that 50% of the isostatic recovery occurred prior to deglaciation, the total postglacial recovery would be in the magnitude of only 15 m. This figure agrees very well with the data obtained on lake levels in the Manyberries-Orion area. The uppermost periglacial lake, Manyberries I, had a northern shoreline elevation of approximately 952 m and a southern elevation of 936 m, suggesting a total rebound of 16 m. The co-incidence between these two figures cannot be explained simply on any other grounds. Isostatic recovery continued to influence the

TABLE 34

Estimates of Isostatic Depression, Canal Creek Area

Location	Feature	Elevation (m)	Distance from Pendant d'Oreille Outlet (935 m) (km)	Elevation Difference (m)	Gradient (m/km) Calculated	Gradient (m/km) Measured	Distance From Ice Front (km)	Total Depression (m)
CC-280a	fluvial sediments	932	2.0	-3	1.50	-	25	38
CC-280b	fluvial sediments	930	3.9	-5	1.28	-	27	35
CC-81	fluvial terrace	928	5.1	-7	1.37	1.3	25	34
CC-281a	fluvial terrace	924	8.3	-11	1.33	1.4	28	37
CC-281c	fluvial sediments	922	9.9	-13	1.31	-	26	34
CC-179	lacustrine beach	935 - 944	0 - 5.3	+9	1.70	1.70	20	34
CC-180	lacustrine beach	935 - 938	0 - 1.8	+3	1.67	1.67	20	33

development of lakes in the Pakowki basin until *c*. 2000 years after deglaciation, after which time it was eclipsed in importance by fluvial downcutting of the southwestern outlet to the Milk River.

The small amount of depression caused by the Phase C glaciation explains why few traces of its effects can be found outside of small, isolated basins such as the Pakowki and Many Islands areas. Despits its relative insignificance during the last glacial event, however, it has proven to be of cricual importance in the understanding of the formation of earlier lake and river phases.

PALAEOSOLS AND SUBAERIAL PALAEOENVIRONMENTS

In the absence of palynological information from the study region, interpretation of palaeosol horizons is the most useful method of gathering information about subaerial palaeoenvironments. These palaeosol horizons can be divided into three major soil sequences: a podzolic-gleysolic catenary association; a sequence reflecting progressive solodization; and a chernozemic - luvisolic sequence. The latter two sequences are also found in the recent soils of the area. Study of these three associations provides valuable information regarding past climatic conditions and depositional environments.

The oldest sequence exposed is the podzolic-gleysolic catenary association (Figure 54). The recharge zone member, an Orthic Humo-Ferric Podzol, is found only in a very restricted zone along the northern escarpment of the Cypress Hills Plateau. At the location where it is best developed, PL-98, it is overlain by a Brunisolic soil of post-Phase C origin. The high montmorillonitic content of the IIBf horizon is especially noteworthy. Although undoubtably derived from material contained in the Cypress Hills conglomerate, the persistance of this material in an unaltered form is intriguing. Jungerius (1966) considered this characteristic, along with the oxidation of iron to the ferric form, to be indicative of warmer, moister conditions that exist at present. Input of material from

FIGURE 54.

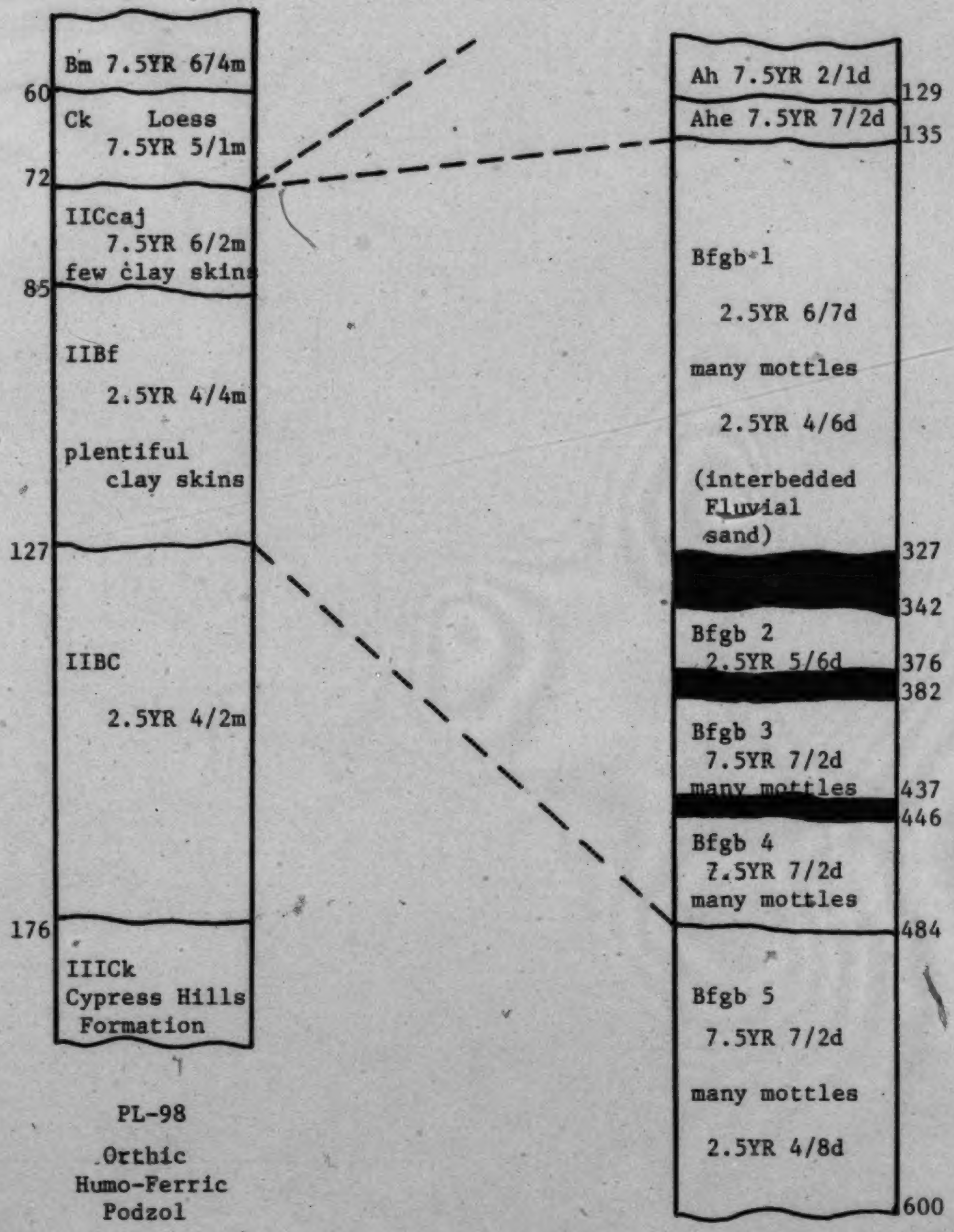
Podzolic Catenary Sequence

The Figure illustrates the two members of the Podzolic Catenary sequence exposed in the Cypress Hills Plateau area. The well- drained member is an Orthic Humo-Ferric Podzol (locality PL-98), and is found on the escarpment edge beneath more recently-developed soils. The downslope member is a Fera Gleysol (locality E-1, Core 4), and is located in a meltwater channel sequence. For further detail, refer to Appendices A (site E-1), I (PL-98), and J (Soil Chemistry).

The diagram indicates the horizon type, Munsell colour, and the presence of clay skins or mottles.

■	Diatomaceous muck
60	Depth below ground surface (cm)

The Figure is not drawn to scale.


Bm 7.5YR 6/4m
60
Ck Loess
7.5YR 5/1m
72
IICcaj
7.5YR 6/2m
few clay skins
85
IIBf
2.5YR 4/4m
plentiful
clay skins
127
IIBC
2.5YR 4/2m
176
IIICk
Cypress Hills
Formation
Ah 7.5YR 2/1d
129
Ahe 7.5YR 7/2d
135
Bfgb 1
2.5YR 6/7d
many mottles
2.5YR 4/6d
(interbedded
Fluvial
sand)
327
342
Bfgb 2
2.5YR 5/6d
376
382
Bfgb 3
7.5YR 7/2d
many mottles
437
446
Bfgb 4
7.5YR 7/2d
many mottles
484
Bfgb 5
7.5YR 7/2d
many mottles
2.5YR 4/8d
600

PL-98
Orthic
Humo-Ferric
Podzol

E-1 core 5
Fera Gleysol

overlying horizons has substantially altered the chemical compositions of the podzolic horizons, making them alkaline in nature (Appendix J). The Humo-Ferric Podzol is described fully in Appendix I.

The lower members of the caternary sequence are the Fera Gleysols found in Cores 3, 4, and 5 at Site DjOn-26(E-1). The presence of mottles and small amounts of gleyed material suggest that these soils formed in areas where the water table fluctuated, either seasonally or over a longer cycle. Since seasonal fluctuations have been shown to be necessary for the production of a podzolic soil (Bennema, 1963, McKeague, 1965), this phenomenon can satisfactorily explain the characteristics present in both members of the catenary sequence.

Similar soils were found by Bennema (1963) to have developed in northern Mediterranean areas, and by McKeague (1965) to be characteristic of well-drained areas of Eastern Ontario. Several factors suggest that the climate under which the sequence developed resembled Eastern Ontario's more than it did the northern Mediterranean's. The diatom horizons associated with the gleysolic soils (Table 35) indicate that the mean annual water temperature was only marginally warmer than at present. The general paucity of humic material suggests an environment dominated by conifers and narrow-leaved deciduous trees such as _Populus_, _Betula_, and _Alnus_. Furthermore, the absence of phytolith forms associated with deciduous trees by Carbone (1977), indeed, the absence of phytoliths in general, indicates that

TABLE 35

Diatom Assemblages Associated with Gleysolic Soils, Site E-1

Sample	Diaton Assemblage		Environment
Core 3 193-198 cm	Microcystis sp. Anabaena sp.	89% 10%	Shallow pond--Eutrophic Cold Temperate
Core 4 393-401 cm	Microcystis sp. Anabaena sp.	86% 12%	Shallow pond--Eutrophic Cold Temperate
Core 5 327-342 cm	Microcystis sp. Anabaena sp. Surirella sp. Aphanizomenon sp.	83% 12% 2% 2%	Shallow pond--Eutrophic Cold Temperate
Core 5 437-446 cm	Microcystis sp. Anabaena sp. Aphanizomenon sp.	77% 21% 2%	Shallow Pond--Eutrophic Cold Temperate

the vegetation was dominated by conifers.

The analogy between a modern climate and a palaeoclimate can never be perfect, principally because the only tools available for such analogies are inaccurate and misleading. Modern vegetative assemblages, purported to reflect modern climates, are compared with ancient vegetative assemblages (or ancient soils believed to have developed under particular assemblages). These ancient vegetative assemblages are then related to ancient climates analogous to modern examples. Thus, every climatic interpretation must satisfy three assumptions (when using soils, four) which in practice are often untrue and always unverifiable. In the present case, it can be seen that the postulated vegetative assemblage does not match the assemblage in the correlated climate region as some broad-leaved genera such as Acer are important constituents of the Eastern Ontario forests (Rowe, 1972). Every single vegetation-climate association can be questioned on similar grounds. Consequently, it is more accurate and less misleading to merely cite general conclusions rather than to stipulate specific conditions. For the podzolic-gleysolic catenary sequence in the Cypress Hills, it can be concluded that at the time of its formation the climate was temperate in nature, somewhat warmer and moister than at present.

Even this limited climatic information enables an estimate of the time of formation of the sequence to be made. The oxidation of the iron within the Podzolic soil indicates that it was formed in a recharge zone. This implies that the Cypress Hills Plateau was a topographic high at this time, meaning that the soil must be younger than the Flaxville gravels in age. This condition implies a Late Pliocene to Holocene age. Since gradual climatic deterioration characterized the Late Pliocene and pre-glacial Quaternary (Shackleton and Opdyke, 1976), and since conditions during the glacial events were not conductive to the formation of Podzolic soils in this area, the soil must be post-Nebraskan. The soil is overlain by loess produced in association with the Phase A glaciation, and so must be older than this event. Thus, these two constraints effectively date the soil as either Aftonian or Yarmouth in age. At present, no basis for choosing between these interglacial periods exists.

Two other pre-Holocene palaeosols have been reported in neighbouring localities, but neither can be directly related to the Cypress Hills palaeosol. Horberg (1954) suggested a Yarmouth or Sangamon age for a soil developed in the Kennedy drift in the Waterton area. The formation of this soil was almost certainly controlled entirely be very local climatic conditions, and conclusions drawn from it would be of value only in the southern Foothills area. In addition, the great thickness (30 m) of the palaeosol suggests that several discrete phases of soil development, and possibly non-pedogenic weathering processes, were involved. David (1966, 1969) reported a pre-Holocene palaeosol at Prelate Ferry, Sask. This soil, a Solodized Solonetz, developed due to local elevation of the water table. Although

PLATE 16. Periglacial Sand Wedge, Locality PL-88d. This sand wedge indicates that periglacial conditions prevailed in the Cypress Hills escarpment area during the Phase A glacial event. The host material is conglomerate of the Cypress Hills Formation. Scale: 1:5

COLOURED PICTURE

this may reflect generally higher water tables throughout the region, and hence a moister climate, this is a tenuous assumption at best. Similar soils are actively forming in the study region under modern climatic conditions.

The chernozem-solonetz sequence is displayed at a number of localities. Some of these soils are exhumed or relic soils, while others are actively developing. No buried solonetzic horizons exist, probably because goundwater conditions would not permit their preservation.

Continuing eluviation of the sodium salts is necessary for the solodization process to operate. If the groundwater regime changes sufficiently to convert a recharge zone to a discharge area, sodium salts will be brought to the surface. Desalinization must then begin anew. In the study region, improper irrigation practices have resulted in the conversion of some low-lying areas into Saline Regosol regions of little agricultural value.

Glacial action has been directly responsible for creating Saline Regosols and Solonetzic soils in several localities within the study area. The isostatic compression of the bedrock caused by the glacial load forced saline brines to the surface under the influence of differential hydrostatic pressures (Grisak _et al_, 1976). This process results in the development of a belt of saline sediments in front of the glacial mass. Since continuation of the advance results in the continuous displacement of the belt, saline sediments are only preserved adjacent to the glacial maxima and lengthy stillstand positions during retreat.

Although this theoretical belt pattern is extremely difficult to recognize in practice, due to the complicating effects of modern solonetzic development and the impossibility of preserving Saline Regosols and Alkaline Solonetzes in recharge zones, the distribution of Solonetzic Chernozems and Solods suggests that the model of Grisak et al (1976) is at least partially correct. These soils, slightly enriched in sodium relative to the Phase B till parent material, are found in ill-defined belts parallel to the major Phase B moraine (Figure 55). The concentration of sodium-rich soils in the northern portion of Medicine Lodge Coulee is especially noteworthy. This section of the meltwater channel, which parallels the Phase B maximum position, contains a greater proportion of sodium-rich soils than does the southern portion of the coulee, which runs obliquely to the former ice front line.

No corresponding solod belt is associated with the Phase C maximum position. The thinness of the Phase C sheet meant that less vertical force was available to create the hydrostatic pressure necessary to generate brine migration. In addition, ice of the Phase C glaciation overlay the Oldman Sandstone, a formation deficient in sodium salts relative to the montmorillonitic Bearpaw Shale, subjected to Phase B glaciation.

The third soil sequence noted in the study region is the Chernozemic - Luvisolic sequence. This sequence developed as a result

FIGURE 55

Solods versus Phase B Limit

The Figure shows the correlation between the Phase B limit in the Elkwater area and the position of Solodic soil in the Cypress Hills Region.

LEGEND

B........ Bain
E........ Elkwater
I........ Irvine
M........ Manyberries
W........ Wild Horse

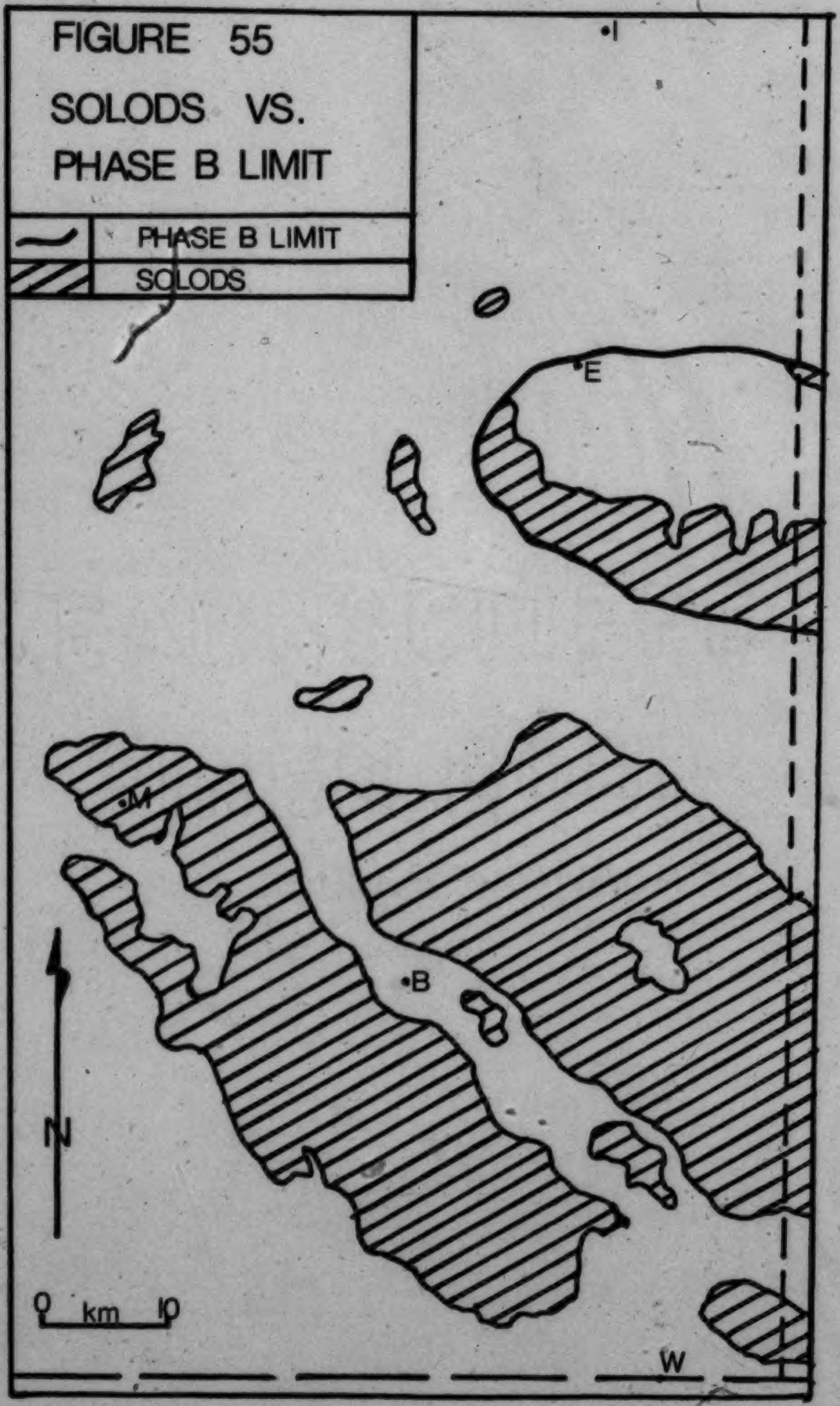


FIGURE 55

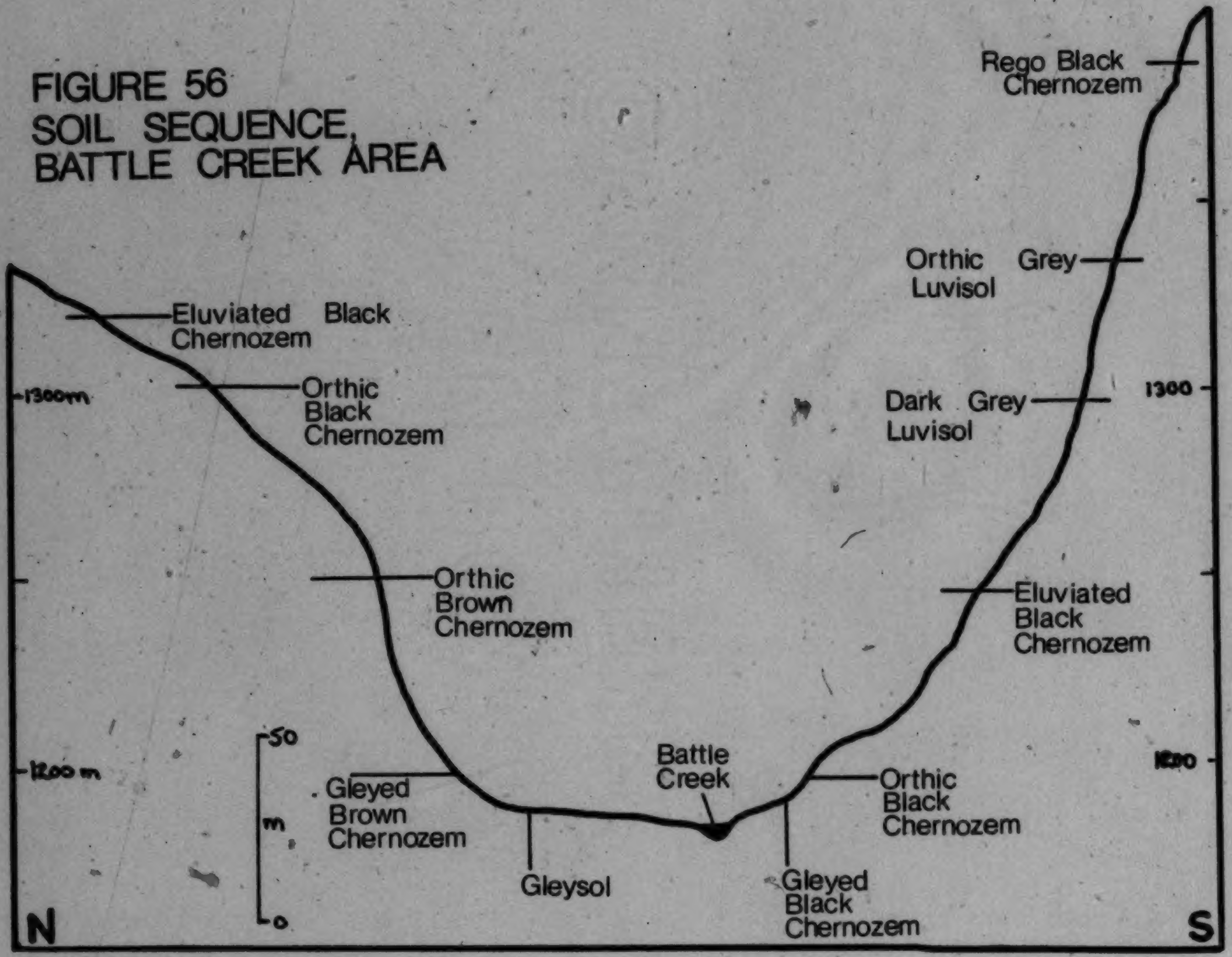
SOLODS VS. PHASE B LIMIT

PHASE B LIMIT
SOLODS
I
E
M
B
W
N
0 km 10

of vegetative transitions. In forested regions such as the northern slope of the Cypress Hills Plateau, the common soils developed are of the Luvisolic Order. In areas dominated by grassland vegetation, Chernozems commonly form. Between these regions is an irregular transition zone, its position constantly shifting in response to climatic and anthropogenic factors (Pettapiece, 1969). The soils of the transition zone lie between the Orthic Black Chernozems of the prairies and the Orthic Grey Luvisols of the Sub-boreal forest. Those displaying some eluviation of clay from the Ah horizon, but still dominantly chernozemic in nature, are termed Eluviated Chernozems. Luvisols with poorly - or moderately - developed Ah horizons are referred to as Dark Grey Luvisols.

On the Cypress Hills Plateau, Jungerius (1966) has recorded three transition events. The most recent of these, a transition from Luvisol to Chernozem, was caused by the clearing of the plateau for pastureland. The subsequent cessation of fire events has limited the ability of Pinus contorta to re-occupy the cleared area (Newsome and Dix, 1969). Both Luvisols and Chernozems are currently found on the plateau (Greenlee, 1978), indicating that total conversion has not occurred. The other pair of transitions noted by Jungerius and the author suggest that the area's climate was initially similar to that at present. Following this period, climatic warming occurred, permitting grassland and chernozem encroachment. This period was then succeeded by gradual cooling, allowing the forest-luvisol association to expand

FIGURE 56
SOIL SEQUENCE,
BATTLE CREEK AREA


Eluviated Black Chernozem
Orthic Black Chernozem
Orthic Brown Chernozem
Gleyed Brown Chernozem
Gleysol
Battle Creek
Gleyed Black Chernozem
Orthic Black Chernozem
Eluviated Black Chernozem
Dark Grey Luvisol
Orthic Grey Luvisol
Rego Black Chernozem
1300m
1200 m
1300
1200
50
m
0
N
S

outward. This climatic phase apparently has continued to the present.

While the climatic record which this soil succession provides is apparently unequivocal, nothing can be concluded regarding the duration of each interval. In a marginal area such as the northern escarpment of the plateau, a comparatively minor alteration of the climate could produce a change in the delicate balance between forest and grassland conditions. Forest fires could also act to clear areas of forest vegetation, permitting temporary grassland encroachment. The absence of charcoal horizons in the northern escarpment sequence discussed above makes it unlikely that fire influenced these specific transitions, but the presence of numerous charred horizons on the south flank of the plateau (Jungerius, 1969) suggests that this process was active in certain areas.

Investigations of palynological sequences and other palaeontological successions in a number of adjacent areas (eg. Dormaar and Lutwick, 1969; Rutter, 1969; Lichti-Federovich, 1970; Schweger *in* Westgate, 1972; Reeves and Dormaar, 1972; Mott, 1972; Fritz and Krouse, 1973; Ritchie, 1976; Delorme *et al*, 1977; Mack *et al*, 1978; Waters, 1979) have established a sequence of climatic events for post-Wisconsin (post-Phase C) time. An initial period of gradual warming after deglaciation culminated, *c*. 8500 B.P., in the development of a climate somewhat warmer and much drier than the present climate. This interval, termed the Altithermal (Antevs, 1948), persisted for approximately 1500 years, during which time most of the lakes of the southern and central prairies became completely dry (Mott, 1972; Schweger, personal communication, 1980). Many rivercourses also were dry during this period, a condition which permitted extensive soil development (Waters, 1979). In the area surrounding the Cypress Hills, most of the major watercourses were apparently dry. The subaerial exposure effectively prevented the preservation of pollen produced at this time, and also contributed to the destruction of grains deposited during the immediate post-glacial period (Terasmae, personal communication, 1979). The sole piece of data relating to the pre-Altithermal period in the study region is a pollen diagram prepared for the Orthic Humic Gleysol horizon exposed at Robinson by Schweger (in Westgate, 1972). The diagram, based on an Ah horizon 30 cm thick, shows a transition from an Artemisia - Ranunculaceae assemblage to one dominated solely by Artemisia. This transition appears to reflect the development of grassland conditions in the region, an indication of the warming and drying trends operative at the time. The radiocarbon date obtained from the Ah horizon, 10230± 150 B.P. (I-4927), agrees with the general timing of the warming trend noted by Reeves and Dormaar (1972) and Ritchie (1976) in adjacent areas.

At Site DjOn-26 (E-1), evidence of climatic warming was obtained from the sediments contained in the cores. The development of multiple soil horizons intersperced with alluvial sand and loess is taken as evidence that water volumes in the streams flowing from the plateau escarpment were generally low at this time. This decreased flow implies that rainfall in the region had declined. Secondly, the upper soil horizons contained abundant elongate and panicoid (Cross-shaped) phytoliths, indicative of tall-grass vegetation (Twis et al, 1969). The encroachment of a tall-grass assemblage into a region formerly dominated by forest vegetation indicates a general climatic amelioration, as has been discussed above. Thus, the uppermost sections of the DjOn-26 cores represent the climatic optimum or Altithermal in this region.

Approximately 7000 B.P., the climate of the southern Canadian prairies began to become cooler and moister. This change caused water tables to rise, streams and lakes to fill, and forests to begin to encroach upon the grassland areas. Increased stream water levels resulted in essentially constant deposition of fluvial silts from c. 7000 B.P. to the present in the Holocene sections studied by Waters (1979). The time of deposition was determined through the stratigraphic relationship between the alluvial sediments and the Mazama ash, deposited isochronically c. 6600 B.P. (Fryxell, 1965).

In the Elkwater area, increased water levels resulted in the formation of the interbedded silt and cultural horizon sequences observed by Gryba (1972, 1975). Deposition throughout this period was relatively constant, short periods of subaerial exposure of the stream channel being represented by the thin artifact-bearing strata. The age of these sediments is given by a radiocarbon date from culture horizon 12a, 7245± 255 (NMC-571) (Gryba, 1975), and by the presence of Mazama ash (Westgate, personal communication, 1980). Thus, this sequence is stratigraphically equivalent to the alluvial silts reported by Waters (1979) and is younger than the uppermost material present in the DjOn-26 cores.

Climatic deterioration has continued to the present time. Current wind patterns (Longley, 1972) favour the gradual development of colder, moister conditions. Although short-term events running counter to the general pattern have occurred in the past, such as the dry conditions of the 1930's, produced by a temporary dominance of south-eastern winds (Schweger, personal communication, 1979), the available records provide no indication that long-term deviations from this pattern will occur in the near future.

SUMMARIAL DESCRIPTION OF SITE DjOn-26

Based upon the nature of the sediments and the correlation of individual horizons, the cores obtained from DjOn-26 can be divided into three groups: an upper, gleysolic group (Cores 3, 4, and 5); a northern, chernozemic groups, in part correlated to the upper series (Cores 1, 2, and 8); and a southern group, with no horizons in common with the other cores (Cores 6 and 7).

The upper gleysolic group cores were formed in a catenary association with the buried Humo-Ferric Podzol exposed on the northern escarpment of the Cypress Hills. During the period of their formation, the water in the main meltwater channel was at a series of falling levels below the second terrace. Consequently, the localities were subjected to fluctuating groundwater levels, which caused the development of the gleysolic soils. Stream flow through the area also fluctuated, producing a series of alternating silt and sand beds. The lower portion of core 3 correlates to the central portions of cores 4 and 5, while the upper portion of core 3 corresponds to the upper portions of the other cores. The relationships among the cores are summarized diagramatically in Figure 58 .

The northern chernozemic group cores encompass the entire development of the site since deglaciation, as the base of the fluvial sequence is exposed in core 2. Throughout most of the early gleysolic phase, these localities remained submerged beneath the water contained in the main channel. As the water level dropped, the streams flowing off the Cypress Hills escarpment extended their channels from the upper area into the northern zone. Consequently, horizons can be correlated between the upper portions of cores 3, 4, and 5, and the middle and

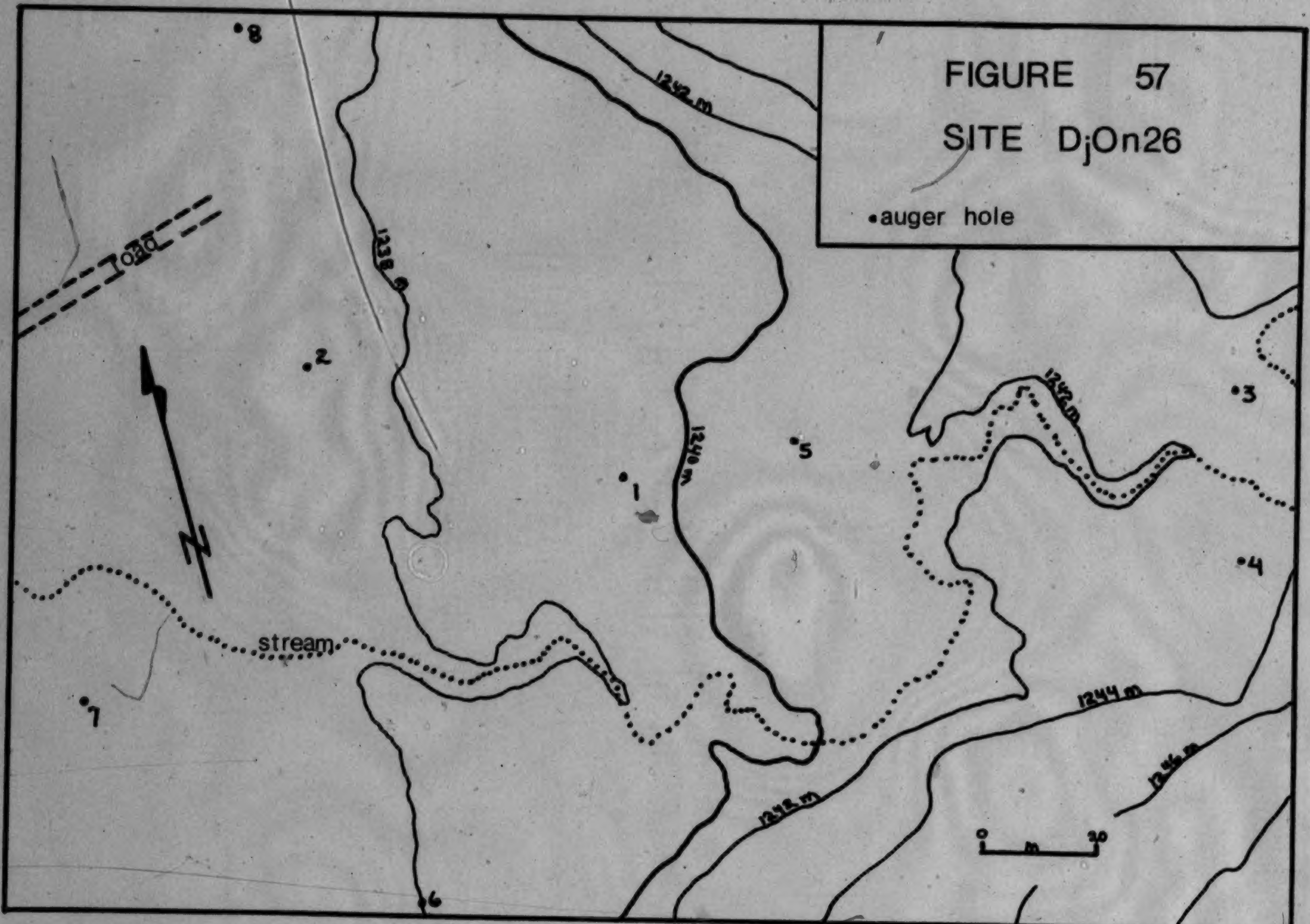


FIGURE 57
SITE DjOn26

•auger hole
1238 m
1240 m
1242 m
1242 m
1242 m
1244 m
1246 m
stream
road
N
1
2
3
4
5
6
7
8
0
m
30

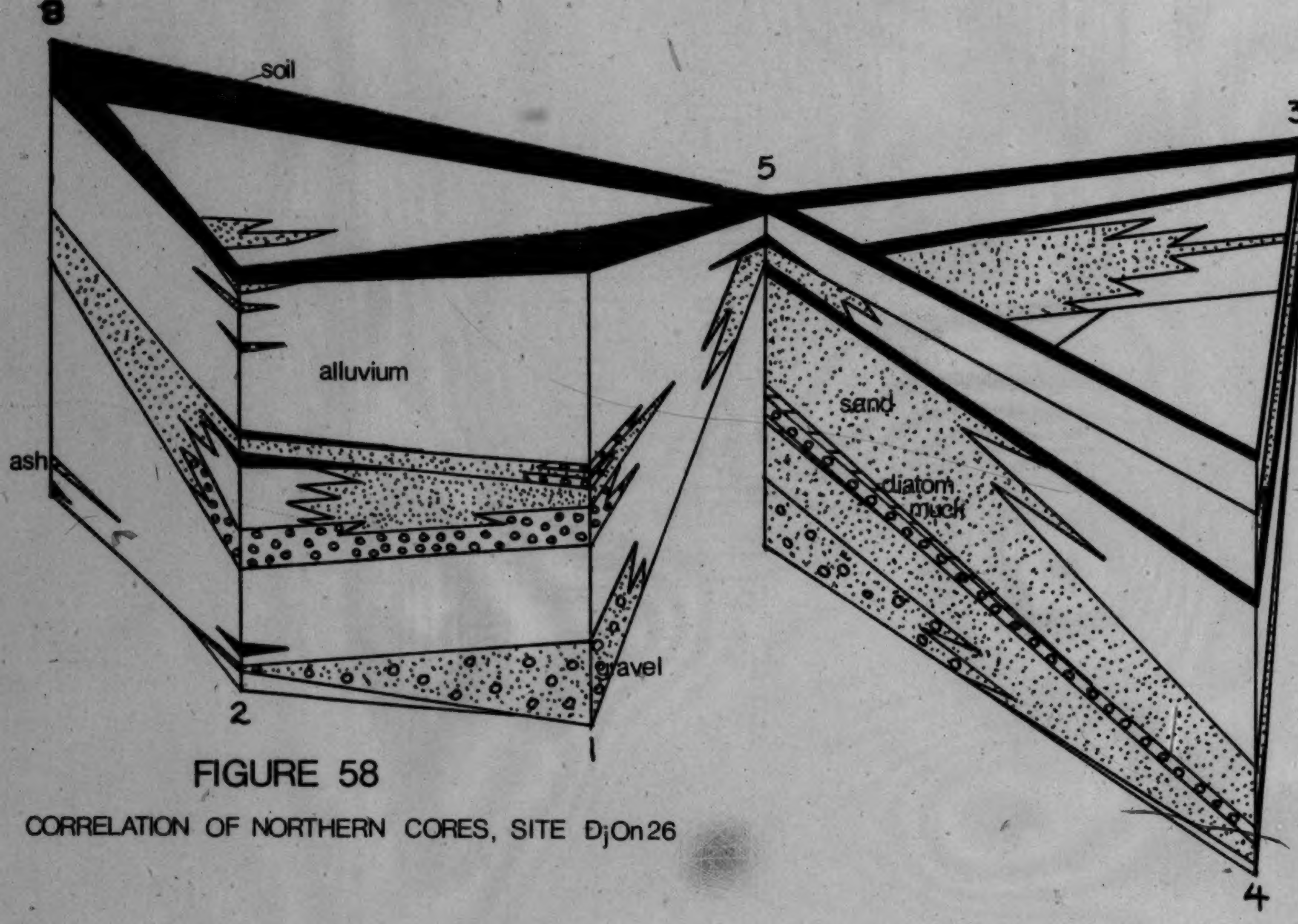

8
soil
5
3
alluvium
ash
sand
diatom muck
gravel
2
1
4

FIGURE 58

CORRELATION OF NORTHERN CORES, SITE DjOn26 upper portions of cores 1, 2, and 8. Figure 58 illustrates the correlations among these six cores.

The southern group cores also record a shifting stream channel pattern, with numerous low-flow stages. The topographic position of these cores with respect to the other six suggests that each group was affected by a different tributary of the main channel. This conclusion is confirmed by the lack of correlatable horizons between the core groups. Figure 59 shows the correlation between the units of cores 6 and 7.

The pit site investigated by Gryba (1975) lies along the divide between the northern and southern cores. Consequently, the lower horizons of the cores cannot be correlated to any horizons exposed in the pit. The most readily-recognized horizon in the pit, the Mazama ash, was not recognized in any of the cores, and no anthropogenic material was recovered. The similarity in mineralogy among the alluvial silt horizons makes correlation of these units in the absence of sand units impossible when they are palaeontologically barren. Correlation between the pit and the cores immediately adjacent to sites where other anthropogenic material has been found, cores 1 and 8, is further hampered by the evident historical disturbance visible in the upper portions of both cores. It appears that the stream which periodically flooded the pit site formed after the channels in which the core sediments were deposited had been largely infilled and abandoned.

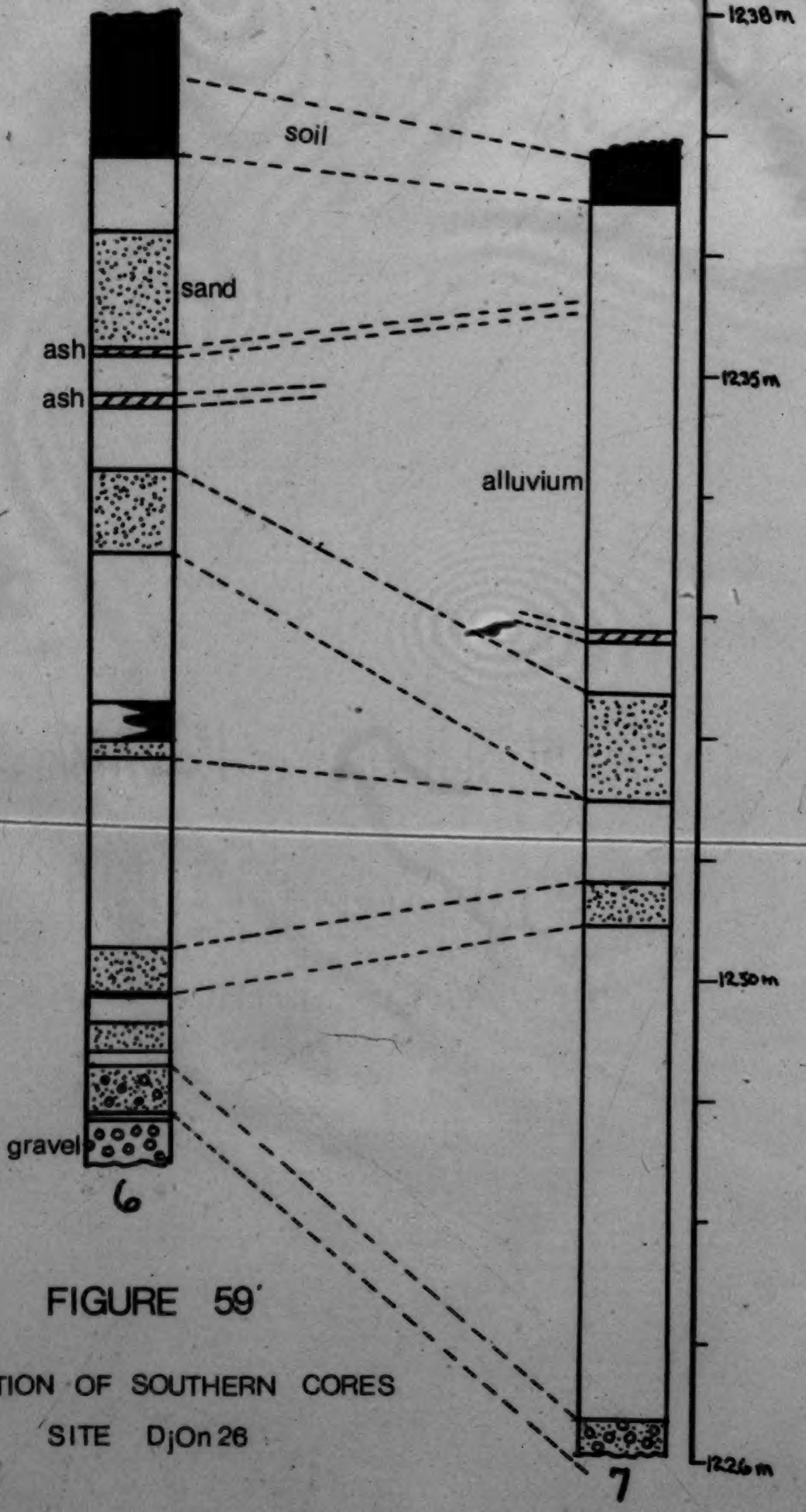

1238 m
soil
sand
ash
ash
1235 m
alluvium
1230 m
gravel
6
1226 m
7

FIGURE 59'

CORRELATION OF SOUTHERN CORES

SITE DjOn 26

CONCLUSION

QUATERNARY HISTORY AND CHRONOLOGY

The Quaternary record of the Western Cypress Hills region spans virtually the entire Quaternary period. Table 36 provides a summary of events in the region.

The first Quaternary deposit preserved in the region was the Humo-Ferric Podzol found along the northern escarpment of the Plateau. Although the exact age of this soil is unknown, the climate at the time of its formation was warmer and moister than that of the present, indicative of an interglacial period. This soil is overlain by loess produced during the Phase A glaciation.

The Phase A glaciation was the most extensive glavial event to affect the study region. The maximum position of the ice front around the Cypress Hills Plateau is depicted in Figure 60. Since the Phase A event is the most extensive, it is considered to be either Kansan or Illinoian in age.

An interglacial or lengthy interstadial intervened between the Phase A and Phase B glaciations. The Phase B event attained a position around the Cypress Hills marked by the Elkwater-Battle meltwater channel and the Green Lake Moraine. The age of this glaciation is considered to be Illinoian or Early Wisconsin. Figure 61 illustrates the maximum extent of the Phase B advance.

Withdrawal of the Phase B glacier created isostatically-controlled depressions which were filled by Lakes Gros Ventre, Wild

TABLE 36 SUMMARY OF QUATERNARY EVENTS, CYPRESS HILLS REGION

Time	Event	Related Sediments and Landforms Formed	Palaeoenvironments and Soils
5000 BP present	minor climatic fluctuations		alteration of luvisols and Chernozems in Plateau escarpment area
5100 BP	-	formation of Elkwater Lake	alternating alluvium and Ah horizons in former meltwater channels
6600 BP	-	Mazama tephra deposited	
c.7500 BP	cooling	reoccupation of basins and channels by water	
c.8500 BP	altithermal	subaerial exposure of Pakowki basin and Elkwater-Battle Channel	warm and dry, Brown Chernozems
c.10000 BP	postglacial warming	Lake Calib	luvisols confined to plateau
c.15000 BP	late Phase C retreat	Lake Ketchum; Many Islands Channels; low water level in Elkwater-Battle Channel	
c.16000 BP	early Phase C retreat	Orion I and II; Seven Persons-Walsh Channel	cool luvisols
c.17000 BP	Phase C Glacial	Etzikom moraine; Manyberries I; Glacier Peak G tephra	
	late Phase B retreat	Lakes Canal Creek and Gahern; westward flow in Elkwater-Battle Channel	
	early Phase B retreat	Lake Wild Horse; eastward flow in Elkwater-Battle Channel; Lake Gros Ventre	
Illinoian or Early Wisconsin	Phase B glacial	Phase B moraine	Salinization of peripheral areas
	Phase A retreat	Formation of Elkwater-Battle Channel	
Kansan or Illinoian	Phase A glacial	Cypress Hills loess	
Aftonian or Yarmouth	interglacial		warm climate Podzolic sequence

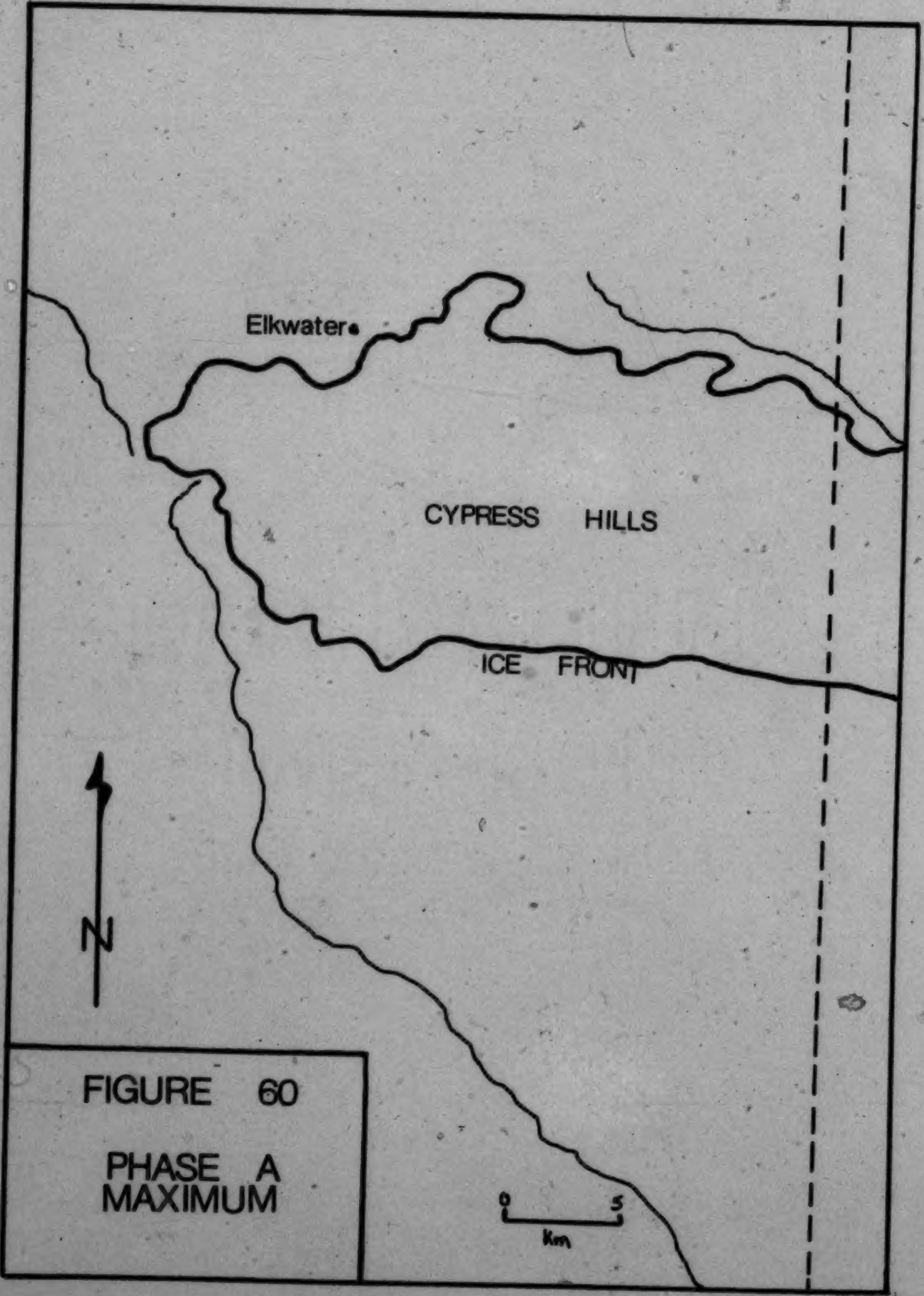

Elkwater
CYPRESS HILLS
ICE FRONT
N
0
5
Km

FIGURE 60

PHASE A MAXIMUM

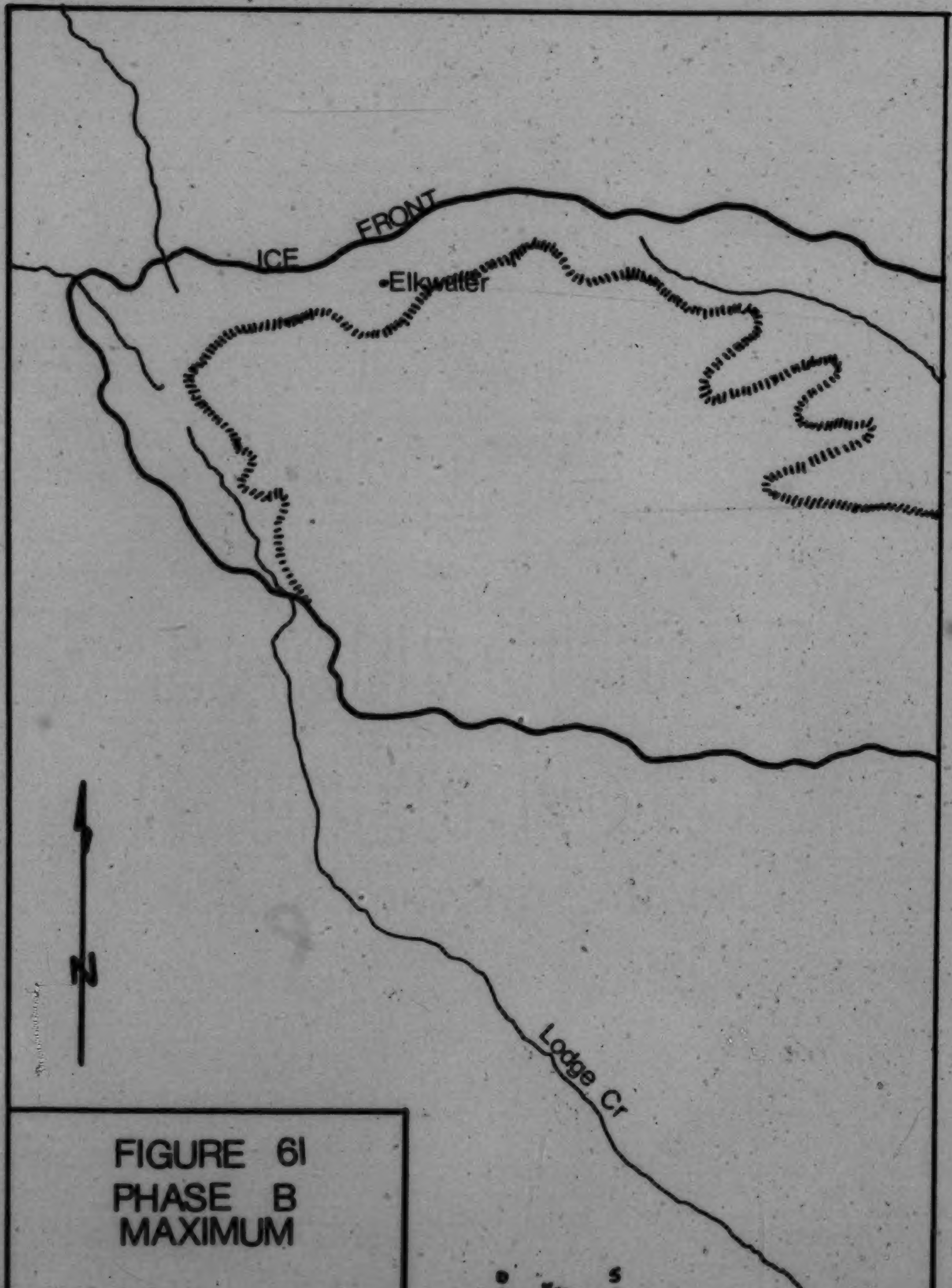


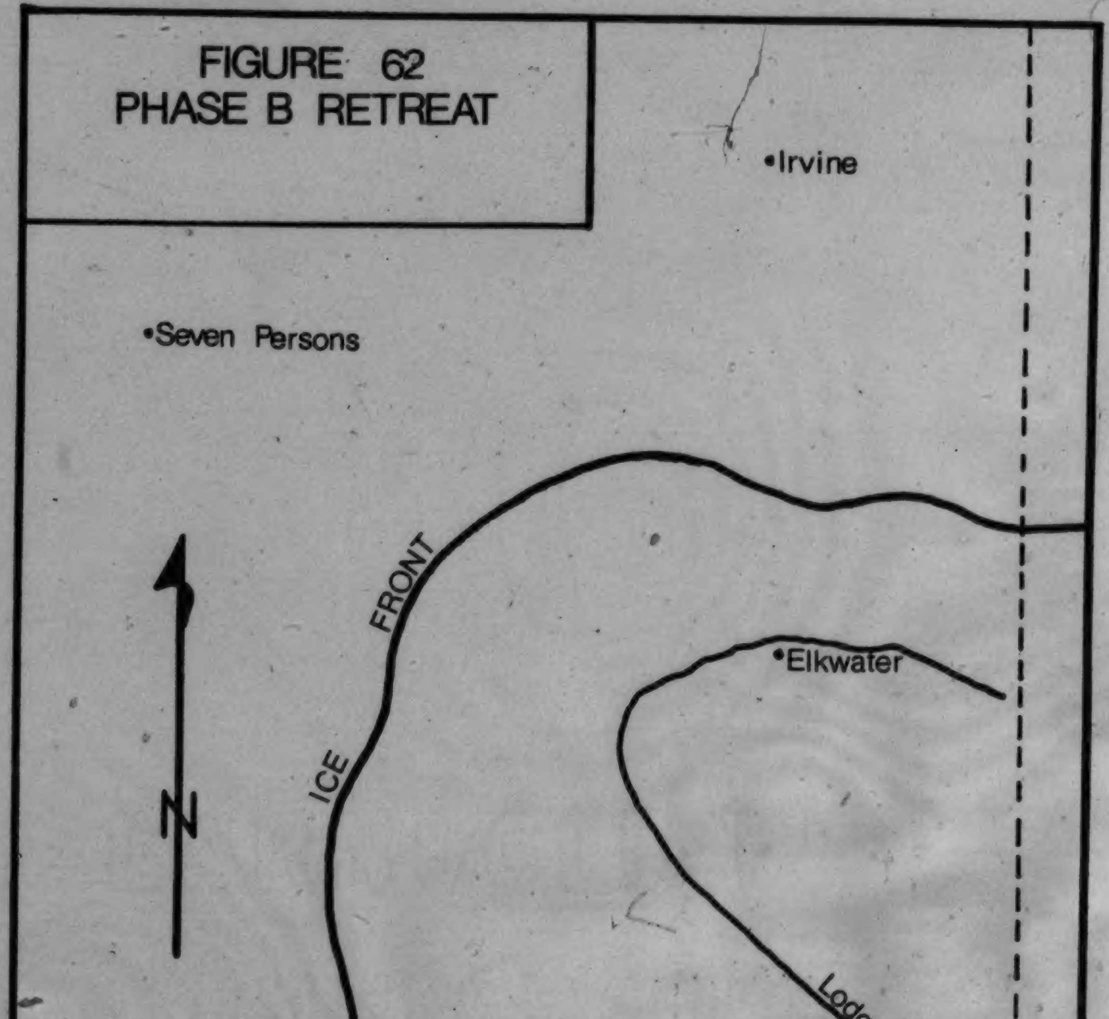
FIGURE 61
PHASE B
MAXIMUM

ICE FRONT
Elkwater
Lodge Cr
N
0 Km 5

Horse, and a succession of lakes in the Pakowki basin (Figure 62). Analysis of the amount of isostatic recovery in the Wild Horse basin indicates that formation of Lake Wild Horse I could not have occurred after the Mid-Wisconsin. Thus the Phase B ice sheet must be of Early Wisconsin or earlier age. Both the lakes in the Wild Horse Basin and those in the Pakowki Basin gradually progressed from an initial oligotrophic condition to mesotrophy, as indicated by phytoplankton assemblages. Although molluscan assemblages preserved in lacustrine sediments suggest that pine forests were present adjacent to some lakes, no relict soils developed under forest conditions exist in the area. The only soils in the region related to deglaciation are the belts of solonetzic chernozems and solods formed through alteration of till saturated with brine forced to the surface by glacio-hydrostatic pressure. In the Cypress Hills area, the Elkwater-Battle channel initially drained Lake Gros Ventre to the east, reversing direction when isostatic recovery and glacial retreat permitted the re-establishment of the Medicine Lodge Channel. High water levels in the Elkwater-Battle channel caused some of the midslope soils of the Humo-Ferric Podzol sequence to be converted to Fera Gleysols.

The Phase C glaciation, achieved its maximum position, marked by the Etzikom moraine, c. 17000 B.P. (Figure 63). Isostatic depression adjacent to the ice front in the Manyberries area caused the ponding of meltwater in Lake Manyberries I. The Glacier Peak G tephra was also deposited in this basin at the same time. The presence of the glacier

FIGURE 62
PHASE B RETREAT


Irvine
Seven Persons
ICE FRONT
N
Elkwater
Manyberries
Lodge Cr.
LAKE
CANAL CREEK I
0 km 10
Alta
Sask
Milk R.
Lost R.
LAKE
WILD HORSE II
Mont

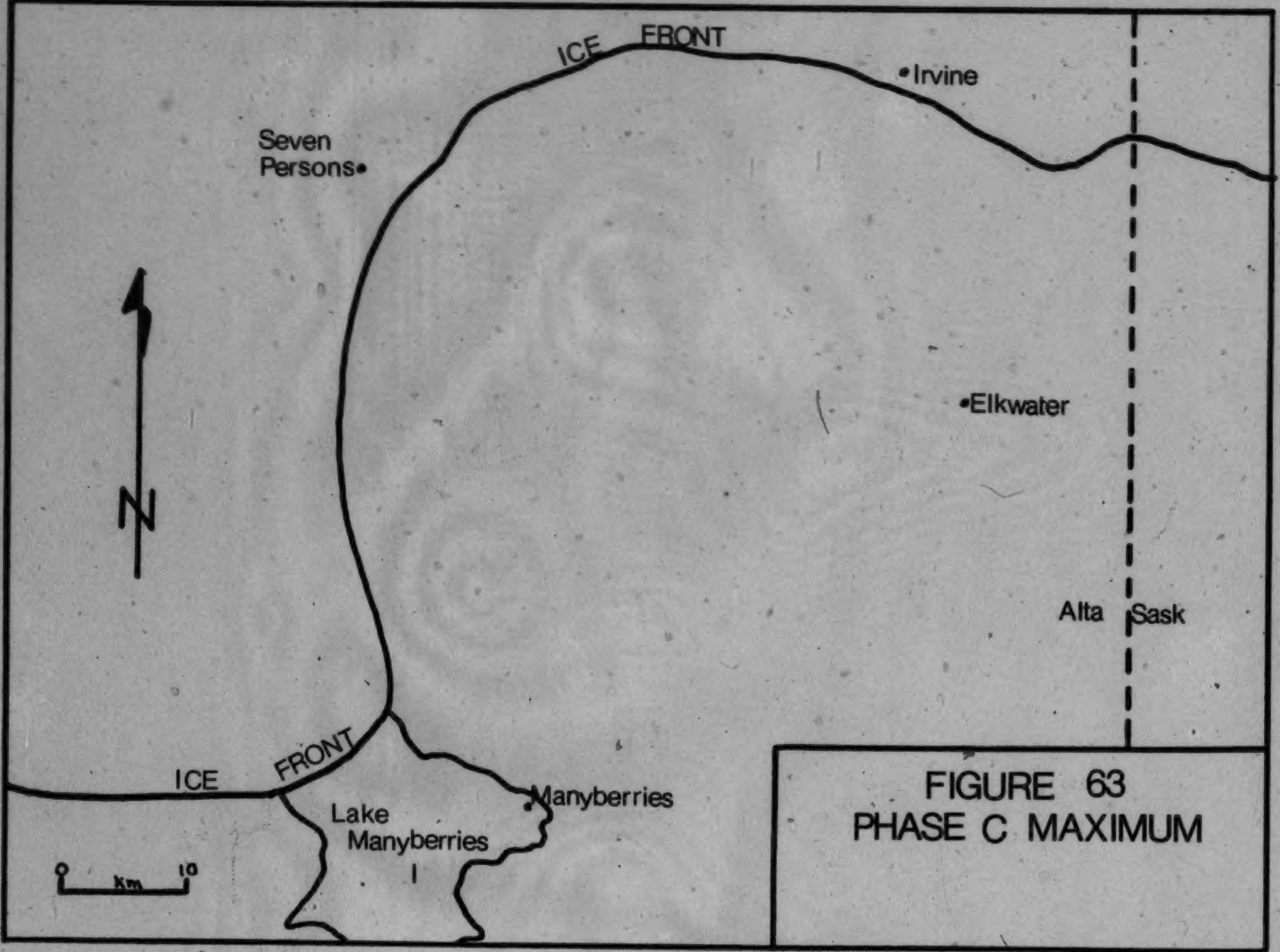

ICE FRONT
Irvine
Seven Persons
Elkwater
Alta
Sask
N
ICE FRONT
Manyberries
Lake Manyberries
I
0 km 10

FIGURE 63
PHASE C MAXIMUM

did not significantly alter the climate in the plateau escarpment area, and no sediments attributable to the Phase C event are recognized in this region.

Retreat of the Phase C glacier caused the formation of a series of lakes in the Pakowki basin. The first of these, Lake Orion I, was oligotrophic in nature. At this time, the Cypress Hills area was under forest cover, permitting the development of luvisols. Subsequent deglaciation and climatic amelioration caused the waters in the Pakowki basin to gradually become eutrophic, lowered the water levels in the Elkwater-Battle and Seven Persons-Walsh meltwater channels, and confined the lubisolic soils to the Cypress Hills Plateau.

Postglacial climatic change resulted in the complete abandonment of the Elkwater-Battle channel and the subaerial exposure of the Pakowki basin. During this warm, dry period, referred to as the Altithermal, loess deposits formed in several areas, including the Many Islands Lake and Wild Horse regions. The Irvine Tephra was deposited during this period in loess sediments south of Many Islands Lake. In the Cypress Hills escarpment area, chernozemic soils developed in former forest zones colonized by grassland vegetation.

Climatic cooling following the Altithermal resulted in the reoccupation of basins and channels by water. Along the plateau's northern escarpment, an alternating sequence of flood events and periods of subaerial exposure resulted in the deposition of alternating alluvial silt beds and Ah soil horizons. The presence of Mazama tephra near the base of this sequence establishes the date of the lower portion at 6600 B.P. Ponding of water in the Elkwater Lake basin began c. 5100 B.P., after the western end of the Elkwater-Battle meltwater channel was blocked by slumped bedrock.

Minor climatic fluctuations have continued over the past 5000 years, producing a sequence of luvisols and chernozems on the Cypress Hills Plateau. The remainder of the study region is characterized by non-depositional conditions, except in lakes and local areas of stream channels. The region supports a number of grassland vegetative assemblages, and Brown and Dark Brown Chernozems are currently developing.

ARCHAEOLOGICAL SIGNIFICANCE

The position of the Phase C maximum indicates that DjOn-26 remained free of glacial ice throughout the Mid- and Late Wisconsin. The earliest possible date for commencement of continuous occupation of the site by man therefore depends upon the time of the beginning of the Phase B retreat. Thus, the site could have been occupied as early as the Sangamon interglacial.

Although there is no direct evidence of human occupation prior to the earliest culture recognized by Gryba (1975), two sites adjacent to the area may provide evidence of Pre-Late Wisconsin human activity. At Medicine Hat, fractured chert pebbles have been recovered from a stratum containing a Sangamon faunal assemblage (Stalker, 1977b). At present, the cause of the fracturing is a matter of some controversy. Although the fracture pattern does not resemble that produced by any natural process (Stalker, 1977b), it cannot be confidently identified as anthropogenic (W. Byrne, Archaeological Survey of Alberta, personal communication, 1980; B. Reeves, University of Calgary, personal communication, 1980).

The other pre-Late Wisconsin man site is located in Mid-Wisconsin sediments at Taber. A juvenile human skull was found at this location in 1961 (Stalker, 1969b), and its inferred stratigraphic position suggests an age of 40,000 BP. Unfortunately, uncertainty exists as to the exact location of the skull in the section. Detailed archaeological study of the site is ongoing, but no additional human remains or artifacts have been recovered from Mid-Wisconsin or earlier horizons.

These data, combined with the existence of an ice-free corridor between the Rocky Mountains and the Late Wisconsin ice sheet, as established by the investigations of Reeves (1973), Stalker (1977, 1980 in preparation), and Jackson (1977, 1979); among other, indicate that man could have been present in the Western Cypress Hills region before the Holocene. If pre-Holocene anthropogenic encampments exist, they would probably be located some distance from the glacier front. The general scarcity of pre-Phase B sediments exposed in the study region suggests that archaeological sites of this age would more likely be found in the complex sections exposed along the South Saskatchewan and Oldman Rivers, or beyond the Phase B limit in Montana. Mid-Wisconsin sites could be located in these areas also, as well as in the Wild Horse - Bain District. No cultural artifacts or human remains were discovered by the author anywhere within the Western Cypress Hill region.

The stratigraphy of the cores obtained from the vicinity of Site DjOn-26, and their relationship to the site investigated by Gryba (1975), is discussed fully in Appendix A. While the cultural horizons are of Mid and Late Holocene age, the uppermost portions of the cores date from the Early Holocene or older. Thus, no direct correlation between the cores and the sediments exposed at the site is possible. However, climatic inferences made from the core sediments indicate that suitable conditions for human occupation of the site have existed from shortly after the conclusion of the Phase B glaciation.

RECOMMENDATIONS

1. Further archaeological research at site DjOn-26 should be carried out immediately north of the pit investigated by Gryba (1975), preferably in the area where test pits were excavated by Gryba (1972). Efforts should be concentrated on the excavation of the upper 3 - 4 m of sediment in these areas, as the results from the deep coring program indicate that no cultural remains are present at depth or in peripheral areas. The presence of Mazama tephra in the region serves as a useful marker unit. However, it must be borne in mind that a) the tephra was most probably not uniformly distributed over the area, and b) that pre-Holocene reworked tephra layers are occasionally present.

2. Archaeological examination of the complex sections along the South Saskatchewan River should take place as soon as is feasible. In particular, the Sangamon horizons containing fractured and chipped chert pebbles should be singled out for special attention.

3. The DjOn-26 pit excavated by Gryba (1975) should be reinforced in order to prevent further deterioration. If possible, the pit should be deepened in order to determine whether additional cultural horizons exist at depth.

4. Future geological investigations should be conducted in the areas surrounding the study region. All of the investigations in surrounding areas to date have concentrated on the complex river sections, and additional data on the prairie areas is urgently required. In particular, an extensive re-investigation of the northern portion

of Montana in the light of data gained not only from this research but also from those of Stalker and Christiansen seems indicated.

5. Comparison of the complex sections along the South Saskatchewan River near Medicine Hat and the relatively simple sections in the study region indicates that an examination of the influence of river valleys upon glacial transport and facies-related deposition is required. The lack of correlation possible between the river and prairie sections suggests that facies relationships are complex and that new correlative techniques are required. The later problem is under active consideration at present by the Alberta Research Council (Proudfoot, personal communication, 1980).

6. The tectonics of glacial motion responsible for the production of the overthrust features southeast of the Pakowki Basin should receive further consideration. Additional drilling and/or seismic investigations in this area could provide information regarding the prevalence and maximum vertical displacement involved in glacial thrusting.

7. The results of this study could be presented to the general public in one or both of two forms: a physical display of artifacts collected from the DjOn-26 site, together with geological material and a graphical/pictorial synopsis of the Quaternary geology of the region; and a brief geological-ethnohistorical guide to the Park Area. Public access to the pit site itself should be restricted until the investigations recommended above are either deferred or conducted.

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APPENDIX A: Site DjOn-26 (E-1)

Stratigraphy of Cores

Core 1 Surface Elevation 1239.53 m

Depth	Sediment Type
0 - 73 cm	Chernozemic Ap horizon, 7.5 YR 2/1 d (Black); clayey silt; abundant tall-grass phytoliths.
73-207 cm	Alluvial silt, 7.5 YR 6/3 d (Light Brown); sand content 20%; structureless.
207-236 cm	Alluvial sandy silt, 7.5 YR 6/4 d (Light Brown); sand content 30%; structureless.
236 - 269	Alluvial clay, 7.5 YR 5/4 d (Brown); sand content 3%; structureless; abundant diatoms present; montmorillonitic.
269 - 305	Alluvial silt, 7.5 YR 5/4 d (Brown); clay content 25%; structureless.
305 - 319	Carbonate accumulation horizon, 10 YR 7/2 d (Light Grey); structureless.
319 - 327	Alluvial silt, 7.5 YR 5/4 d (Brown): Clay content 25%; structureless.
327 - 406	Alluvial clay, 7.5 YR 5/4 d (Brown); interbedded with 2 cm laminae of alluvial sand, 7.5 YR 6/3 d (Light Brown) at 20 cm intervals; abundant diatoms present in clay, few diatoms in sand; montmorillonitic.
406 - 412	Gravel - pebble bed.
412 - 431	Alluvial sand, 7.5 YR 6/4 d (Light Brown); structureless.
431 - 440	Gravel - pebble bed.
440 - 476	Alluvial sand, 7.5 YR 6/4 d (Light Brown); structureless.
476 - 543	Gravel - pebble bed; driller's notes indicate that water table lies at top of this unit.
543 - 562	Alluvial clay, 7.5 YR 6/4 d (Light Brown); sand content 3%; structureless; montmorillonitic.
562 - 566	Alluvial silt, 7.5 YR 6/4 d (Light Brown); sand content 6%; clay content 7%; structureless; montmorillonitic.
566 - 599	Alluvial clay, 7.5 YR 6/5 d (Light Brown); sand content 7%; structureless; montmorillonitic.

599 - 680	Alluvial clay; 7.5 YR 6/4 d (Light Brown); interbedded with 2 cm laminae of alluvial silt, 7.5 YR 6/4 d (Light Brown) at 20 cm intervals; few diatoms present in clay, none in silt; montmorillonitic.
680 - 686	Alluvial sandy silt, 7.5 YR 6/5 d (Light Brown); sand content 30%; structureless.
686 - 714	Alluvial clay, 7.5 YR 6/4 d (Light Brown); sand content 15%; montmorillonitic.
714 - 855	Gravel - pebble bed.
855 +	No sample. Drillers* report "layer of muck above hard clay and small stones".

* Drilling records as reported to Parks Planning Division, October, 1978.

Interpretation: This core represents a typical channel sequence. Initial rapid flow conditions (lowermost gravel bed) are succeeded by alternating periods of very low flow (clay) and slightly increased flow (silt). The presence of the diatom assemblages in the clays indicates that conditions in the stream were oligotrophic to mesotrophic, with nutrient input increasing through time.

Renewed vigourous stream activity is indicated by the gravel and sand units between 406 - 543 cm. The absence of diatoms from the clay beneath these units, and the abruptness of the transition, suggests that the stream returned to its original channel following a period of relative inactivity and subaerial exposure. Such events are common in instances where the stream width is much less than the valley width. Subsequently, another sequence of clay and silt was produced by alternating flow regimes, as discussed above. The carbonate accumulation layer was formed by groundwater activity, and represents a period when the overlying sediment was subaerially exposed.

Core 2 Surface Elevation 1237.37

Depth	Sediment Type
0 - 28 cm	Chernozemic Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; abundant phytoliths.
28 - 35 cm	Alluvial sand, 7.5 YR 6/4 d (Light Brown); structureless.
35 - 56 cm	Alluvial clay, 7.5 YR 5/4 d (Brown); sand content 7%; structureless.
56 - 63	Alluvial sand, 7.5 YR 6/3 d (Light Brown); structureless.
63 - 69	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; granular structure.
69 - 94	Alluvial silt and interbedded sand, 7.5 YR 5/3 d (Brown); distorted bedding; clay content 10%.
94 - 99	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; granular structure.
99 - 120	Alluvial silt, 7.5 YR 5/3 d (Brown); distorted bedding with sand laminae; clay content 35%.
120 - 132	Gravel - fine pebble bed.
132 - 176	Alluvial clay, 7.5 YR 5/4 d (Brown); sand content 20%; structureless.
176 - 207	Carbonate accumulation horizon, 10 YR 7/2 d (Light Grey); structureless; clay content 60%.
207 - 275	Alluvial clay, 7.5 YR 5/4 d (Brown); interbedded with alluvial sand, 7.5 YR 6/3 d (Light Brown); bedding poorly defined, irregular thicknesses.
275 - 283	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; granular structure.
283 - 315	Alluvial sand, 7.5 YR 5/3 d (Brown); structureless.
315 - 326	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; structureless.
326 - 356	Alluvial silt and sand, 7.5 YR 5/3 d (Brown); interbedded; structure poorly defined.
356 - 368	Carbonate accumulation horizon, 10 YR 8/1 d (White); structureless.

368 - 442	Alluvial clay, 7.5 YR 5/4 d (Brown); interbedded with minor lenses of alluvial sand and silt, 7.5 YR 6/4 d (Light Brown), and organic-rich diatomaceous muck, 7.5 YR 3/1 d (very dark Grey); bedding poorly defined; diatoms indicate fluvial, oligotrophic conditions.
442 - 512	Gravel - pebble bed, with occasional sandy lenses and laminae; structureless.
512 - 554	Organic-rich diatomaceous muck, 7.5 YR 3/1 d (very dark Grey); structureless; clay content 65%; charcoal flakes present, apparently aeolian-transported.
554 - 638	Alluvial clay interbedded with sand, silt, and diatomaceous muck, as for 368 - 442.
638 - 644	Carbonate accumulation horizon, 10 YR 8/1 d (White); compacted; structureless; carbonate content 67%.
644 - 661	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; structureless.
661 - 675	Alluvial silt, 7.5 YR 5/4 d (Brown); structureless; charcoal flake present.
675 - 686	Gravel - pebble bed.
686 - 713	Alluvial silt, 7.5 YR 5/6 d (Strong Brown); structureless.
713 +	Drillers report confused stratigraphy with mottled black and red clay, bone, pebbles, and sand. This description could fit either a till unit derived from the Frenchman and Ravenscrag formations, or a colluviated unit of the same provenance. In either case, the base of the fluvial sequence has been reached.

Interpretation: Once again, the sedimentary succession implies a constantly-shifting channel system. Periodic subaerial exposure of the site is indicated by the development of Ah soil horizons. The presence of diatomaceous muck indicates very shallow ponds with abundant organic input. It appears that this area has been peripheral to the main channel throughout most of its recorded history. Possibly, it represents a swamp or marsh with fluctuating water levels. Occasional channel events are indicated by the gravel lenses.

The charcoal flakes noted at 512 - 554 cm and 668 cm were undoubtably transported to the site by aeolian action. Their shapes preclude fluvial transport, and the absence of other wood material militates against *in situ* deposition. The absence of cultural material and the position of the flakes near the base of the core suggest that they were produced as a result of natural fires, not anthropogenic ones.

Core 3 Surface Elevation 1243.78 m

Depth	Sediment Type
0 - 12 cm	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; granular structure; abundant tall-grass phytoliths; estimated thickness prior to compression.
12 - 60 cm	Alluvial silt, 7.5 YR 6/4 d (Light Brown); structureless; estimated thickness prior to compression; Bm horizon.
60 - 75 cm	Ah horizon, 7.5 YR 2/1 d (Black): clayey silt; granular structure; tall-grass phytoliths common; estimated thickness prior to compaction.
75 - 120 cm	Alluvial silt, 7.5 YR 5/3 d (Brown), with many medium prominent mottles, 2.5 YR 5/6 d (Red); structureless; estimated thickness prior to compression; Bmj horizon.
120 - 131 cm	Alluvial silt, as above; true thickness.
131 - 140 cm	Diatomaceous muck, 7.5 YR 4/0 d (Dark Grey); structureless.
140 - 158 cm	Alluvial silt, as above.
158 - 168 cm	Alluvial sand, 5 YR 6/6 d (Reddish-Yellow); structureless.
168 - 193 cm	Alluvial silt, as above.
193 - 198 cm	Diatomaceous muck, 7.5 YR 3/0 d (Very Dark Grey); structureless.
198 - 209 cm	Alluvial silt as above.
209 - 223 cm	Alluvial silt, 7.5 YR 5/2 d (Brown), with many medium prominent mottles, 2.5 YR 5/6 d (Red), and small amounts of gleyed material 7.5 YR 7/2 d (Pinkish-Grey); structureless.
223 - 242 cm	Alluvial silt; 7.5 YR 7/2 d (Pinkish-Grey), with many medium prominent mottles, 2.5 YR 5/6 d (Red); structureless.
242 - 272 cm	Alluvial sand, 2.5 YR 6/8 d (Light Red); structureless; interbedded gravel lenses.
272 + cm	Gravels reported by drillers; no sample

Interpretation: The sequence displayed in the lower portion of the core indicates that the energy level of the stream was gradually declining.

The position of the site, near the headwater area, suggests that the stream's energy declined as a result of infilling and a decreased gradient, rather than as a result of lateral channel shifting. The lower portion of this core is thus apparently younger than the lower portions of cores 4 and 5.

The central portion of the core records a series of rising and falling water levels. Low water is reflected in the development of the diatomaceous muck layers, while the sand units indicate high-energy flooding.

Soil development in the core can be subdivided into two phases. The lower portion of the core displays a sequence of gleyed and mottled horizons. These are usually indicative of a fluctuating water table. The mottled horizons probably developed in association with the relatively low water levels associated with the deposition of the diatomaceous muck. When the water level in the stream rose, mottling caused by subaerial oxidation ceased. The reducing environment beneath the stream bed produced ferrous ions, causing the silt and sand below the diatomaceous muck to become grey in colour and hence gleyed. Gleysation did not affect the sediment being deposited along the stream bed, of course, because this environment was not conducive to the reduction of ferric iron.

Gleysols usually posses three distinct zones: an upper, organic-rich zone (diatomaceous muck); a middle zone characterized by both mottling and gleying, and a lower zone where only gleying is present. The absence of the third zone reflects a major change in the groundwater regime of the area. Initially, the water table was high, during which time the gleysol was formed. Subsequent climatic changes, which caused a decrease in the amount of moisture available to the region, caused the site of core 3 to become a groundwater recharge zone, rather than a fluctuating area. Consequently, the formerly gleyed sediments were oxidized, the mottles remaining in their original state. These soils can be classified as Fera Gleysols, and represent the downslope member of a palaeo-catenary sequence. The recharge zone member is the red podzolic soil exposed near the surface of the Cypress Hills Plateau (PL-98).

The upper portion consists of a series of alternating flood-plain deposits and organic-rich Ah horizons. Each Ah horizon marks the top of a former soil. Since these horizons are more than 10 cm thick, the soils can be classified as Black Chernozems. The presence of Bm horizons below each soil enable them to be termed Orthic Black Chernozems. This soil subgroup is currently developing on the plateau surface.

Core 4 Surface Elevation 1243.20 m

Depth	Sediment Type
0 - 30 cm	Ah horizon, 7.5 YR 2/1 d (Black); clayey silt; granular structure; few tall-grass phytoliths.
30 - 60 cm	Alluvial silt, 7.5 YR 6/4 d (Light Brown); structureless; estimated thickness prior to compression; Bm horizon.
60 - 73	Alluvial silt as above; true thickness.
73 - 82	Ah horizon, as above.
82 - 89	Ah horizon, 7.5 YR 2/1 d (Black) with few fine faint mottles, 7.5 YR 6/4 d (Light Brown); structureless.
89 - 98	Ah horizon, 7.5 YR 2/1 d (Black); granular structure.
98 - 120	Alluvial silt, 7.5 YR 6/4 d (Light Brown); structureless.
120 - 180	Alluvial silt, 7.5 YR 5/4 d (Brown) with few medium prominent mottles, 2.5 YR 5/6 d (Red); two indistinct dark bands (7.5 YR 3/1 d) present at base and top of succession, both badly contorted and distorted by compression; total thickness estimated.
180 - 212	Bt horizon, 7.5 YR 5/3 d (Brown); clay content approximately 60 - 70%; no structure preserved; some clay skins on particles 7.5 YR 6/4 d (Light Brown).
212 - 239	Alluvial silt, 7.5 YR 5/3 d (Brown) with many medium prominent mottles, 2.5 YR 5/6 d (Red); structureless.
239 - 249	Ah horizon, as above.
249 - 314	Alluvial silt, as above.
314 - 322	Carbonate accumulation horizon, 10 YR 8/1 d (White); structureless.
322 - 390	Alluvial silt, as above.
390 - 393	Alluvial clay, 7.5 YR 5/2 d (Brown) with many medium prominent mottles, 2.5 YR 5/6 d (Red); structureless.
393 - 401	Diatomaceous muck, 7.5 YR 4/0 d (Dark Grey); structureless.
401 - 540	Alluvial silt, 7.5 YR 5/2 d (Brown); with many medium prominent mottles, 2.5 YR 5/6 d (Red), and small amounts of gleyed material, 7.5 YR 7.2 d; (Pinkish Grey); structureless.

540 - 596	Alluvial sand, 2.5 YR 6/7 d (Light Red); structureless; clay content 6 - 9%.
596 - 660	Alluvial sand, 2.5 YR 6/7 d (Light Red); structureless; occasional thin gravel beds; clay content 0%.
660 - 668	Gravel - pebble bed, with sand content approximately 70%.
668 - 704	Alluvial sand, 2.5 YR 6/7 d (Light Red); structureless; clay content 5 - 10%.
704 - 711	Alluvial silt, as above.
711 +	Drillers report gravel; no sample.

Interpretation: This core is a more lengthy and complete sequence of the type found in core 3, and discussed in detail above. Its position downslope from core 3 accounts for the greater number of events recorded (more probability for river fluctuation and channel shifting, especially early in the stream's development). The upper portion of the core shows a systematic development of a chernozemic soil interrupted by periodic flooding events. These floods may have removed weakly consolidated organic-rich material on occasion, such as the Ah horizon associated with the development of the Bt horizon between 180 - 212 cm. Classification depends upon the thickness and number of Ah horizons. The sequence displayed between 60 and 120 cm is a Cumulic Regosol, while the uppermost soil is an Orthic Black Chernozem.

Core 5 Surface Elevation 1241.01 m

Depth	Sediment Type
0 - 27 cm	Ah horizon, 7.5 YR 2/1 d (Black); clay; granular structure; few tall-grass phytoliths.
27 - 65 cm	Alluvial clay, 7.5 YR 5/4 d (Brown); structureless.
65 - 78	Ah horizon, as above; no phytoliths.
78 - 120	Alluvial sand, 7.5 YR 5/4 d (Brown); structureless.
120 - 129	Ah horizon, as above; no phytoliths.
129 - 135	Ahe horizon, 7.5 YR 7/2 d (Pinkish Grey); 65% sand; structureless.
135 - 327	Alluvial sand, 2.5 YR 6/7 d (Light Red); interbedded with alluvial sand, 7.5 YR 7/2 d (Pinkish Grey) with many medium prominent mottles, 2.5 YR 4/6 d (Red); structureless.
327 - 342	Diatomaceous muck, 7.5 YR 4/0 d (Dark Grey); structureless.
342 - 376	Gravel - sand bed; sand 2.5 YR 5/6 d (Red); gravel content 35%.
376 - 382	Diatomaceous muck, 7.5 YR 4/0 d (Dark Grey); structureless.
382 - 437	Alluvial sand, 7.5 YR 7/2 d (Pinkish Grey), with many medium prominent mottles, 2.5 YR 4/8 d (Red); structureless; clay content 3%.
437 - 446	Diatomaceous muck, as above.
446 - 484	Alluvial sand, as above.
484 - 600	Gravel - sand bed, 10% pebbles, sand 7.5 YR 7/2 d (Pinkish Grey) with many medium prominent mottles, 2.5 YR 4/8 d (Red); structureless; gravel content 40%.
600 +	Drillers report gravels to a depth of 680 cm.

Interpretation: The sequence displayed resembles in general terms, that found in cores 3 and 4. The position of these cores above the second terrace found in the channel suggests that the gleysolic soils and the terrace development are related. A river surface at or near the second terrace level would permit the gleysation and mottling of the cores to proceed. Based upon the texture and composition of the sediment, and the degree of development of the mottling the 3-4-5 region would have to have been a recharge zone for several considerable periods of time. Therefore, a major river level below the terrace is more probable. The absence of a suitable lower terrace suggests steadily - declining water levels. As outlined in the section dealing with Fluvial Deposits and Landforms, this terrace is considered to have formed during the retreat from the Phase A and/or Phase B maxima.

The lower soils of the core are Fera Gleysols, similar to those of cores 3 and 4. The presence of an Ahe horizon (129 - 135 cm) indicates that slow recharge conditions prevailed at the time of its formation, again suggesting river levels below the second terrace. The uppermost soils are Rego Black Chernozems, characterised by the development of thick Ah horizons directly above alluvial material, without an intervening Bm or Bt horizon.

Core 6 Surface Elevation 1238.0

Depth	Sediment Type
0 - 20 cm	LFH horizon, 7.5 YR 3/1 d (Very Dark Grey); littermat containing pine needles and recent human debris.
20 - 44	Ahe horizon, 7.5 YR 6/4 d (Light Brown); sand content 30%; structureless.
44 - 50	Aej horizon, 7.5 YR 7/4 d (Pink); sand content 55%; structureless.
50 - 55	Ah horizon, 7.5 RY 3/1 d (Very dark Grey); granular structure; abundant tall-grass phytoliths.
55 - 63	Ahe horizon, as above.
63 - 77	Ah horizon, as above.
77 - 88	Ahe horizon, as above.
88 - 93	Aej horizon, as above.
93 - 115	Ah horizon, as above.
115 - 133	Alluvial silt, 7.5 YR 6/3 d (Light Brown); structureless.
133 - 140	Ah horizon, as above; no phytoliths.
140 - 169	Alluvial silt, as above.
169 - 181	Ah horizon, as above, no phytoliths.
181 - 272	Alluvial sand, 7.5 YR 6/4 d (Light Brown); structureless.
272 - 280	Volcanic ash, 7.5 YR 8/1 d (White); shards badly weathered; 95% silt-sized material; large amount of non-volcanic detritus.
280 - 316	Alluvial silt, as above.
316 - 327	Volcanic ash, 7.5 YR 8/1 d (White); shards badly weathered; 90% silt; large amounts of non-volcanic detritus.
327 - 340	Alluvial clay, 7.5 YR 5/4 d (Brown); few diatoms; structureless.
340 - 345	Ah horizon, as above; no phytoliths.
345 - 366	Alluvial clay, as above.

366 - 377	Alluvial silt, as above.
377 - 380	Alluvial sand, as above.
380 - 390	Diatomaceous muck, 7.5 YR 3/0 d (Very Dark Grey); structureless.
390 - 405	Alluvial sand, 7.5 YR 3/2 d (Dark Brown); several diatoms; structureless.
405 - 412	Diatomaceous muck, as above.
412 - 440	Alluvial sand, as above.
440 - 442	Diatomaceous muck, as above.
442 - 445	Alluvial sand, as above.
445 - 498	Alluvial silt, 7.5 YR 4/4 d (Dark Brown); structureless.
498 - 570	Alluvial clay, 7.5 YR 4/4 d (Dark Brown); structureless.
570 - 575	Ah horizon, 7.5 YR 3/1 d (Dark Grey); structureless.
575 - 583	Alluvial clay, as above.
583 - 588	Ah horizon, as above.
588 - 595	Alluvial clay, as above.
595 - 600	Ah horizon, as above.
600 - 615	Alluvial sand, 7.5 YR 3/2 d (Dark Brown); structureless.
615 - 772	Alluvial silt, as above; minor sand and clay interbeds.
772 - 812	Alluvial sand, 7.5 YR 3/2 d (Dark Brown), intersperced with pods of alluvial silt, 7.5 YR 4/4 d (Dark Brown) and volcanic ash, 7.5 YR 8/1 d (White): ash impure, silt content 96%; minor pebbles also present in unit.
812 - 836	Alluvial silt, as above; minor sand and clay interbeds.
836 - 861	Alluvial sand, 7.5 YR 3/2 d (Dark Brown); structureless; gravel and pebble content 10%.
861 - 869	Alluvial clay, as above; strongly compacted.
869 - 880	Alluvial sand and gravel, as above.
880 - 903	Gravel - pebble bed.

903 - 912	Alluvial sand and gravel, as above.
912 - 916	Alluvial clay, 7.5 YR 5/2 d (Brown); weathered and oxidised; compacted; structureless.
916 - 944	Gravel - pebble bed.

Interpretation: This core reflects a large number of river shifts, changes in water levels, and climatic alteration. The lowermost unit, a gravel - pebble bed, was deposited either in the main meltwater channel stream bed, or in a tributary formed shortly after the main channel dropped below this level. The abundance of Shield crystalline rocks and Palaeozoic carbonates indicates that the glacier responsible for carrying these clasts to the site area was still nearby, and thus provided a ready source of distal material.

Overlying this unit is a badly-weathered alluvial clay layer, deposited during a lower flow period. The manner in which this clay is weathered suggests that it has undergone a lengthy period of subaerial exposure without the establishment of any vegetation upon it. This in turn indicates that climatic conditions were harsh at this time. A periglacial environment thus accounts for both the lower units.

The central portion of the core (115 - 912 cm) records alternating water levels caused by the shifting of channels. The topography of the region, as well as the slope of gravel and sand beds correlated between this core and core 7, suggests that the entire sequence was deposited in a relatively low energy braided stream environment. The dominance of silt over sand and gravel in the sequence is indicative of relatively low energy.

The relative scarcity of crystalline and Palaeozoic carbonate clasts, the absence of weathered clay horizons, the diatom assemblages present in the muck layers, the nature of the phytoliths in the Ah horizons, and the chemical characteristics of these soil units all suggest that this sequence formed under climatic conditions similar to those currently found in the area. The only major difference in climate was that the amount of moisture available was somewhat greater during the dormation of the sequence. The great difference in climatic conditions apparent between this sequence and the lower weathered clay stratum suggests that a significant portion of climatic and stratigraphic history has been removed from the record, probably by the high-energy stream responsible for the deposition of the overlying gravel and sand units (869 - 912 cm). Thus, the central portion of the core is much younger than the lower section. On the basis of the periglacial nature of the lower sequence, it is considered to have developed almost immediately after the Phase A maximum. The central portion of the core apparently spans the entire period from the retreat from the Phase B maximum to the Latest Wisconsin - Early Holocene and may in fact span even more time.

The three volcanic ash layers were reworked by fluvial action from either the Ravenscrag bedrock or glacially-transported material. Due to the forested nature of the surrounding area, and the amount of colluvial and alluvial deposits mantling the bedrock, no bedrock exposures could be located in the recharge or upslope areas.

The upper portion of the core formed during the Early- to Mid-Holocene, and consists of an alternating series of Ah, Ahe and Aej horizons. The entire sequence, classed as a Cumulic Humic Regosol, apparently formed as soil development was interrupted at irregular intervals by the deposition of loess. During soil formation some of the silt in the loess deposited during the previous aeolian-dominated interval was eluviated, forming the Ahe and Aej horizons. No horizon remains sufficiently unaltered to warrant designation as a B or C unit. The prevalence of loess, and its scarcity in metamorphic minerals, suggests that it formed during the Mid-Holocene, a moisture-deficient period in the region.

Core 7 Surface Elevation 1236.85 m

Depth	Sediment Type
0 - 44 cm	LFH horizon, 7.5 YR 3/1 d (Very Dark Grey); littermat containing pine needles.
44 - 73 cm	Alluvial silt, 7.5 YR 5/2 d (Brown); structureless.
73 - 85 cm	Ah horizon, 7.5 YR 3/1 d (Very Dark Grey); granular structure.
85 - 127 cm	Alluvial silt, as above.
127 - 130 cm	Ah horizon, as above.
130 - 141 cm	Alluvial silt, as above.
141 - 144 cm	Ah horizon, as above.
144 - 149 cm	Alluvial silt, as above.
149 - 151 cm	Ah horizon, as above.
151 - 168 cm	Alluvial silt, as above.
168 - 171 cm	Aej horizon, 7.5 YR 7/4 d (Pink); sand content 70%; structureless.
171 - 193 cm	Alluvial silt as above.
193 - 194 cm	Ah horizon, as above.
194 - 211 cm	Alluvial silt, as above.
211 - 213 cm	Ah horizon, as above.
213 - 225 cm	Alluvial silt, as above.
225 - 229 cm	Ah horizon, as above.
229 - 240 cm	Alluvial silt, as above.
240 - 243 cm	Ah horizon, as above.
243 - 249 cm	Alluvial silt, as above.
249 - 250 cm	Ah horizon, as above.
250 - 300 cm	Alluvial silt, as above.
300 - 306 cm	Ah horizon, as above.
306 - 314 cm	Ahe horizon, 7.5 YR 6/4 d (Light Brown); sand content 43%; structureless.

314 - 397 cm	Alluvial silt, as above.
397 - 412 cm	Volcanic ash, 7.5 YR 8/1 d (White); shards badly weathered; 90% silt; large amounts of non-volcanic detritus.
412 - 416 cm	Alluvial silt, as above.
416 - 419 cm	Ah horizon, as above.
419 - 434 cm	Alluvial clay, 7.5 YR 5/4 d (Brown); structureless.
434 - 437 cm	Diatomaceous muck, 7.5 YR 3/1 d (Very Dark Grey); structureless.
437 - 448 cm	Alluvial clay, as above.
448 - 452 cm	Diatomaceous muck, as above.
452 - 540 cm	Alluvial sald, 7.5 YR 6/4 d (Light Brown); structureless; minor silt beds.
540 - 600 cm	Alluvial silt, 7.5 YR 5/4 d (Brown); core very poorly preserved.
600 - 610 cm	Ah horizon, as above.
610 - 643 cm	Alluvial sand, 7.5 YR 6/4 d (Brown); structureless; barren; interbedded with several thin (1 cm) diatomaceous muck bands, 7.5 YR 3/0 d (Very Dark Grey).
739 - 745 cm	Diatomaceous muck, 7.5 YR 3/0 d (Very Dark Grey); structureless.
745 - 780 cm	Alluvial silt, 7.5 YR 5/4 d (Brown) structureless; barren.
780 - 1080 cm	Alluvial silt, as above. Core very poorly preserved. Drillers report minor sand and clay bands throughout this interval. Bedded sands and gravels are reported at 1050 - 1080 cm; these were not recognized due to the state of deterioration of the core. Pebbles found scattered throughout.
1080 + cm	Drillers report sand and gravel unit to 1200 cm; no sample.

Interpretation: Cores 6 and 7 can be correlated to each other, but not to any other cores in the area. Correlation on the basis of clast content in the lowest sand and gravel unit of Core 7 indicates that this horizon is the same as the second-lowest gravel unit of Core 6. The identification is tentative, due to the state of deterioration of Core 7 below 780 cm. Thus, the lowermost periglacial unit of core 6 was not encountered in core 7.

The entire sequence from 0 - 780 cm can be explained by envisaging an alternating pattern of high and low stream flows, channel abandonment, and occasional subaerial exposure, leading to the development of Ah horizons. In terms of soil classification, the entire sequence is a Cumulic Regosol.

Within the sequence, several sand units occur. Many of these have been correlated to topographically higher units in core 6. The general correlatability of these horizons may indicate that cores 6 and 7 lay in the same subchannel of the stream system. The possibility that only a single channel was present throughout this time can be rejected because the low flow events do not correlate. For example, the development of diatomaceous muck horizons in the topographically lower core 7 location should be reflected by subaerial exposure at core 6. Hence, Ah horizons should form there at the same times as the muck forms in core 7. However, this is not observed. At various stratigraphic locations, flow at core 6 was greater than at core 7; at others, the reverse situation prevails.

As was the case for core 6, the single volcanic ash horizon in core 7 cannot be assigned to a definite provenance. The diversity of minerals present suggests that more than one bedrock stratum served as a source for the material. The absence of Holocene and Wisconsin shards means that no definite age can be assigned to the material.

The absence of an upper Ah horizon suggests that soil development at core 7 has been retarded. The LFH horizons are slightly decomposed at the surface, becoming more decomposed at depth. Although the lower portion of the horizons is not sufficiently altered to enable it to be classified as an organic horizon, it is apparent that a fibric or mesic horizon was developing. This suggests that the locality was occupied by the fringes of a swamp during the period immediately following the deposition of the alluvial sequence. During the moisture-deficient period in the Mid-Holocene, the swamp probably ceased to exist. However, the sediment, if exposed, would be unsuitable for aeolian transport. Furthermore, the area would remain covered by vegetation, preventing both the deposition and transport of loess in the core 7 locality. Thus, the alternating loess-soil sequence exposed in core 6 is equivalent to only a very small portion of core 7.

The swampy nature of the locality as visible at present appears to have effectively hindered the development of a Chernozemic soil. The soil is presently developing from a Regosol into a Fibrisol, under year-round water-saturated conditions.

Core 8 Surface Elevation 1237.38 m

Depth	Sediment Type
0 - 84 cm	Ap horizon, 7.5 YR 2/1 d (Black); recent human debris; granular structure.
84 - 89 cm	Alluvial silt, 7.5 YR 5/4 d (Brown); structureless.
89 - 96 cm	Ah horizon, 7.5 YR 2/1 d (Black); granular.
96 - 150 cm	Alluvial silt, as above.
150 - 180 cm	Gravel bed; no sample.
180 - 191 cm	Ah horizon, as above; several tall-grass phytoliths.
191 - 240 cm	Alluvial silt, as above.
240 - 250 cm	Ah horizon, as above.
250 - 257 cm	Alluvial silt, as above.
257 - 262 cm	Ah horizon, as above.
262 - 265 cm	Alluvial silt, as above.
265 - 267 cm	Ah horizon, as above.
267 - 273 cm	Carbonate accumulation horizon, 7.5 YR 7/1 d (Light Grey); structureless.
273 - 276 cm	Alluvial silt, as above.
276 - 278 cm	Ah horizon, as above.
278 - 307 cm	Alluvial silt, as above.
307 - 392 cm	Alluvial sand, 7.5 YR 6/4 d (Light Brown); structureless.
392 - 398 cm	Diatomaceous muck, 7.5 YR 3/1 d (Very Dark Grey); structureless.
398 - 441 cm	Alluvial clay, 7.5 YR 4/4 d (Dark Brown); structureless.
441 - 711 cm	Alluvial silt, 7.5 YR 5/2 d (Brown); few fine prominent mottles, 2.5 YR 4/4 d (Reddish-Brown); irregular bands of alluvial clay, 7.5 YR 5/2 d (Brown) and alluvial sand, 7.5 YR 5/4 d (Brown); barren.
711 - 715 cm	Diatomaceous muck, as above.

715 - 727 cm	Alluvial silt, as above.
727 - 741 cm	Volcanic ash, 7.5 YR 8/1 d (White); shards badly weathered; 90% silt; large amounts of non-volcanic detritus.
741 - 768 cm	Alluvial silt, as above.
768 - 776 cm	Volcanic ash, as above.
776 - 784 cm	Alluvial silt, as above.
784 + cm	Drillers report sand, grading downwards to gravels; no samples.

Interpretation: Several of the lower silt, sand and gravel horizons of core 8 can be correlated to units exposed in cores 1, 2, 4 and 5, suggesting that these locations were all within the limits of the stream system which developed after the withdrawal of the main channel from the second terrace level. No correlation of the volcanic ash layers is possible, however. The entire sequence can be described as a fluvial deposit characterized by alternating energy levels, fluctuating and shifting channels and periodic subaerial exposure resulting in the development of Ah soil horizons. The uppermost soil is an Orthic Black Chernozem, while the horizons below can be grouped as a Cumulic Regosol.

APPENDIX B: Chemistry of Tephra Strata

Location	Stratum	Fe_2O_3	Na_2O	K_2O	Cl	SiO_2
IR-27a	Oldman-lower	0.98%	2.11%	2.26%	0.10%	
IR-27b	Oldman-upper	0.95	2.05	2.35	0.10	
MB-15a	Oldman	1.12	2.30	2.12	0.13	
B-183a	Oldman	1.16	2.35	2.25	0.11	
B-183b	Bearpaw-1*	2.01	2.33	2.31	0.15	
MB-15c	Bearpaw-2	4.87	2.26	2.37	0.17	66. %
MB-15d	Bearpaw-3	3.11	2.18	2.42	0.15	69.
MB-15e	Bearpaw-4	2.50	2.20	2.36	0.13	
MB-15f	Bearpaw-5	1.96	2.37	1.81	0.16	
MB-16c	Bearpaw-6	4.03	2.20	2.46	0.19	
MB-15g	Bearpaw-8	1.78	4.36	1.67	0.09	
IR-27b	Bearpaw-B**	3.99	2.36	1.74	0.13	
IR-27c	Bearpaw-D	4.63	2.20	2.41	0.11	
IR-27e	Bearpaw-J	2.98	2.36	2.64	0.12	
IR-27f	Bearpaw-K	3.33	2.25	2.46	0.20	
PL-103a	Bearpaw-V	5.00	2.21	2.29	0.13	
PL-103c	Bearpaw-X	1.06	2.20	2.33	0.14	
PL-103d	Bearpaw-CC	3.75	2.31	1.50	0.15	
PL-103e	Eastend	3.82	2.22	2.36	0.14	
E-34	Eastend	2.41	2.18	2.44	0.15	
W-118	Whitemud	4.09	2.71	1.04	0.29	
PL-103f	Whitemud	3.22	2.53	0.82	0.25	
FW-213a	Battle	0.90	4.36	0.87	0.09	82.
E-34	Battle	0.65	0.94	0.80	0.04	80.
PL-104	Kneehills Tuff	0.86	0.96	0.62	0.03	91.
BH-139	Kneehills Tuff	0.97	1.20	0.73	0.05	

Location	Stratum	Fe_2O_3	Na_2O	K_2O	Cl	SiO_2
ML-141	Kneehills Tuff	0.92%	0.96%	0.64%	0.04%	
29-24-29-18-W4	Kneehills	0.88	1.09	0.68	0.06	89. %
ML-5	Ravenscrag	5.39	4.37	0.86	0.09	75.
FW-211	Ravenscrag	2.73	2.20	0.99	0.09	
FW-212	Ravenscrag	1.39	2.52	1.39	0.05	
FW-213	Ravenscrag	1.81	2.59	2.06	0.11	80.
PL-112ff	Ravenscrag	2.96	4.86	1.96	0.16	
IR-27f	Bearpaw***	3.33	2.32	2.66	0.13	
PL-103c	Bearpaw	1.00	2.20	2.28	0.14	
MB-16c	Bearpaw	4.11	2.15	2.52	0.20	
MB-16c	Bearpaw	4.09	2.12	2.44	0.22	
MB-16c	Bearpaw	4.13	2.15	2.47	0.18	
MB-15q	Bearpaw	3.21	2.17	2.39	0.15	69.
PL-103b	Whitemud***	3.26	2.50	1.01	0.31	
FW-213g	Battle***	0.99	4.26	0.84	0.03	
FW-212	Ravenscrag***	1.37	2.54	1.37	0.06	80.
FW-211	Ravenscrag	2.69	2.17	1.06	0.11	
B-182	Unknown***	1.86	2.91	1.18	0.12	
GV-237	Unknown	1.92	1.88	1.22	0.12	
JD-278	Unknown	2.23	4.26	1.39	0.12	
MI-268	Irvine	1.02	3.92	3.41	0.15	
MB-11	Glacier Peak G	1.18	3.94	3.37	0.16	
E-1	Mazama	2.15	5.20	2.61	0.18	
E-1b	Mazama	2.12	5.19	2.59	0.17	
W-50	Mazama	2.14	5.11	2.62	0.17	
T-149a	Mazama	2.17	5.21	2.58	0.18	

Location	Stratum	Fe_2O_3	Na_2O	K_2O	Cl	SiO_2
El-core 6(E)	Upper ash Unknown	2.89	2.39	1.55	0.15	
El-core 6(F)	Middle ash Unknown	4.02	1.22	1.32	0.11	
El-core 6(N)	Lower ash Unknown	3.09	2.64	1.62	0.14	
El-core 7(G)	Unknown	3.03	1.96	1.01	0.12	
El-core 8(M)	Upper ash Unknown	4.55	2.41	1.61	0.16	
El-core 8(M)	Lower ash Unknown	3.83	2.03	1.62	0.09	

* Number of bed measured from base of formation by Russell & Landes (1940).

** Letter of bed measured from base of formation by Crockford (1951).

*** Reworked.

APPENDIX C: Mineralogy of Tephra Strata

Location	Stratum	Refractive Index				Other
		Shards	Hblde^{o}	Opx.^{o}	Cpx.^{o}	Minerals
IR-27a	Oldman-lower		1.647-51	1.688		abimz
IR-27b	Oldman-Upper		1.649	1.690	1.691	abimz
MB-15a	Oldman		1.672	1.691	1.691	abcgmz
B-183a	Oldman		1.655	1.689		aimz
B-183b	Bearpaw-1*		1.663	1.693	1.685	bcimuz
MB-15c	Bearpaw-2		1.659	1.688	1.688	aimuvz
MB-15d	Bearpaw-3		1.664	1.692	1.690	imz
MB-15e	Bearpaw-4		1.659	1.695	1.686	imuz
MB-15f	Bearpaw-5		1.653	1.689	1.687	bcmz
MB-16c	Bearpaw-6		1.663	1.692	1.688	abcgm
MB-15g	Bearpaw-8		1.648	1.690	1.687	bcgmz
IR-27b	Bearpaw-B**		1.653	1.692	1.690	imz
IR-27c	Bearpaw-D		1.660	1.692		imuz
IR-27e	Bearpaw-J		1.666	1.690	1.692	acimuz
IR-27f	Bearpaw-K		1.662	1.693	1.687	cimz
PL-103a	Bearpaw-V		1.650	1.695	1.688	abgmvz
PL-103c	Bearpaw-X		1.662	1.693	1.690	cimuv
PL-103d	Bearpaw-CC		1.646	1.688	1.690	bimuz
PL-103e	Eastend		1.650	1.692	1.686	bgmr
E-34	Eastend		1.664	1.693	1.692	abgimz
W-118	Whitemud		1.660	1.689		imz
PL-103f	Whitemud		1.655	1.691		imuvz
FW-213a	Battle		1.659	1.692		imrz
E-34	Battle		1.658	1.692		imz
PL-104	Kneehills			1.691	bmz	

Location	Stratum	Shards	Hblde	Opx.	Cpx.	Others
BH-139	Kneehills					mz
ML-141	Kneehills			1.691		imz
29-24-21-18-W4	Kneehills			1.691		mz
ML-5	Ravenscrag		1.659	1.688	1.686	abgimrz
FW-211	Ravenscrag		1.662	1.691		aimuvz
FW-212	Ravenscrag		1.649	1.693	1.691	acimvz
FW-213d	Ravenscrag		1.668	1.692	1.685	bcimuz
PL-112ff	Ravenscrag		1.658	1.692	1.687	abgimuvz
IR-27f	Bearpaw***		1.653	1.688	1.686	acimuz
PL-103c	Bearpaw***		1.649	1.695	1.688	abgmvz
MB-16c	Bearpaw		1.663	1.692	1.688	abcgm
MB-16c	Bearpaw		1.663	1.692	1.688	abcgm
MB-16c	Bearpaw		1.663	1.692	1.688	abcgm
MB-15p	Bearpaw		1.664	1.691	1.690	imz
MB-15q	Bearpaw		1.665	1.692	1.690	imz
IR-27h	Bearpaw		1.668	1.689	1.692	acimuz
PL-103b	Whitemud***		1.656	1.691		imuvz
FW-213g	Battle***		1.659	1.692		imrz
FW-212	Ravenscrag***		1.649	1.693	1.691	acimvz
FW-211	Ravenscrag		1.662	1.690		aimuvz
W-114	Unknown***		1.668	1.689	1.691	cgimz
B-182	Unknown		1.646	1.690	1.686	bgimuz
GV-237	Unknown		1.659	1.691	1.690	aimva
JD-278	Unknown		1.660	1.689		bcimrz
MI-268	Irvine	1.497-506	1.643	1.695		bgimu
MB-11	Glacier Peak G	1.500-503	1.645	1.694		bgimu

Location	Stratum	Shards	Hblde	Opx.	Cpx.	Others
E-1	Mazama	1.499-509	1.658	1.689	1.686	abgimz
E-1b	Mazama	1.499-509	1.659	1.690	1.686	abgimz
W-50	Mazama	1.500-509	1.661	1.691	1.687	abgimz
T-149a	Mazama	1.499-509	1.660	1.690	1.687	abgimz
El-core 6(E)	Upper ash Unknown		1.656	1.690	1.689	abgimuz
El-core 6(F)	Middle ash Unknown		1.653	1.689	1.692	acgimuz
El-core 6(N)	Lower ash Unknown		1.657	1.693	1.690	acimuvz
El-core 7(G)	Unknown		1.651	1.689	1.692	bimruz
El-core 8(M)	Upper ash Unknown		1.652	1.692	1.690	abimuz
El-core 9(M)	Lower ash Unknown		1.650	1.690	1.688	abcimuvz

List of mineral abbreviations for Appendix C

a	apatite
b	biotite
c	cummingtonite
g	garnet
i	ilmenite
m	magnetite
r	rutile
u	ulvospinel
v	chevkinite
z	zircon

*	Number of bed measured from base of formation by Russell & Landes (1940).
**	Letter of bed measured from base of formation by Crockford (1951).
***	Reworked.
o	Refractive index is n_x modal value

Appendix D Textural Analyses

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
1B 12-18	Alluvium	15.4	7.2	well	sym
1B 28-32	"	20.6	6.8	"	"
1B 45-40	"	20.3	5.0	"	"
1C 5-10	"	14.2	5.8	"	"
1C 16-20	"	16.9	4.1	"	"
1C 37-42	"	17.4	3.9	"	"
1D 0-5	"	20.3	5.0	"	"
1D 23-28	"	24.0	5.9	"	"
1D 42-49	"	9.8	27.3	"	"
1D 56-60	"	3.9	45.6	moderate	mod +
1E 5-10	"	5.7	36.5	mod. well	"
1E 12-17	"	2.5	44.8	moderate	"
1E 24-29	"	3.1	44.2	"	"
1F 0-5	"	15.8	24.6	"	"
1F 12-17	"	10.2	26.1	"	"
1F 35-41	"	13.2	32.6	"	"
1G 7-12	"	24.8	14.3	"	sym
1G 15-20	"	17.8	35.9	"	mod +
1G 20-25	"	6.4	44.5	"	"
1G 33-38	"	15.4	34.4	"	"
1G 48-52	"	25.9	13.3	"	mod -
1H 0-6	"	20.6	24.1	"	sym
1H 12-17	"	97.3	0.2	very well	mod -
1H 23-27	"	31.6	3.8	well	sym
1I 5-10	"	98.7	0.0	very well	mod -
1J 20-25	"	3.1	41.8	moderate	mod +
1J 40-44	"	5.9	7.2	very well	sym

1J 46-51	"	2.8	23.8	well	"
1K 0-5	"	3.9	39.6	moderate	"
1K 7-12	"	7.4	48.8	"	"
1K 12-17	"	11.5	19.6	well	"
1K 26-32	"	6.9	47.6	moderate	"
1K 40-45	"	10.2	49.4	"	
1L 12.16	"	3.2	54.6	"	mod +
1L 3.136	"	11.5	49.4	"	sym
1M 10-15	"	17.4	11.0	well	"
Core 2					
2B 15.20	Alluvium	63.8	7.3	well	mod -
2B 45-50	"	19.9	33.2	moderate	sym
2C 0-12	"	95.2	0.5	very well	"
2C 20-25	"	23.6	41.5	moderate	"
2D 0-18	"	2.0	60.6	well	"
2E 8-17	"	55.8	15.6	well	"
2E 33-39	"	65.2	4.0	well	"
2E 46-52	"	4.3	20.1	"	"
2F 6-15	"	61.2	1.0	"	mod -
2F 25-32	"	36.6	2.2	moderate	sym
2G 8-12	"	3.9	35.7	"	"
2G 15-22	"	1.2	62.8	well	"
2H 3-11	"	35.6	17.8	moderate	"
2H 17-22	"	33.7	21.4	"	"
2H 50-60	"	97.9	0.0	very well	"
2J 15-22	"	2.0	35.7	well	"
2J 35-44	"	19.3	21.8	"	"
2K 19-28	"	35.6	8.7	"	"

2K 28-34	"	11.7	50.9	moderate	mod +
2K 46-50	"	21.8	35.9	"	"
2L 3-15	"	22.3	24.6	"	sym
2L 30-34	"	26.3	20.9	"	"
2L 36-43	"	39.4	41.8	"	"
2L 44-50	"	27.8	31.9	"	"
Core 3					
3B 0-15	"	30.0	20.2	"	"
3C 5-11	"	35.4	23.6	"	"
3C 38-48	"	93.5	1.2	very well	"
3D 13-18	"	36.2	24.2	moderate	"
3D 34-43	"	35.7	22.5	"	"
3D 45-52	"	88.7	3.9	very well	mod -
3D 60-72	"	90.0	2.5	"	mod -
Core 4					
4D 5-10	"	7.0	60.2	well	mod -
4D 22-29	"	6.2	73.7	"	mod +
4D 40-46	"	35.7	7.6	"	sym
4E 14-21	"	35.7	15.2	well	"
4E 33-39	Alluvium	12.9	22.1	well	sym
4E 42-50	"	1.0	10.4	very well	"
4F 0-4	"	7.8	16.9	"	"
4F 20-27	"	35.6	15.2	mod.well	"
4F 41-48	"	33.9	18.4	"	"
4G 10-15	"	36.2	14.1	"	"
4G 29-32	"	11.8	56.5	"	"
4G 33-36	"	29.8	19.9	"	"
4G 45-50	"	30.2	20.6	"	"

4H 20-26	"	33.6	12.9	"	"
4H 48-53	"	37.6	6.7	"	"
4I 12-16	"	34.3	14.7	"	"
4I 33-36	"	30.2	19.8	"	"
4I 45-52	"	38.9	12.8	"	"
4J 1-5	"	48.3	8.6	"	"
4J 12-20	"	54.3	2.9	"	"
4J 26-31	"	69.8	8.9	"	"
4J 40-44	"	65.2	5.9	well	"
4K 0-15	"	88.9	1.9	very well	mod +
4K 26-32	"	96.8	0.7	"	sym
4K 44-50	"	95.3	0.7	"	mod +
4K 50-60	"	94.5	0.5	"	sym
4L 1-8	"	62.6	6.2	well	"
4L 11-18	"	45.8	11.6	mod.well	"
4L 24-31	"	45.7	3.8	"	"
4L 32-44	"	66.8	4.3	"	"
Core 5					
5C 15-22	"	60.7	13.9	"	"
5C 25-33	"	91.2	1.2	well	"
5C 48-52	"	61.3	12.9	"	"
5D 15-19	"	73.9	3.1	"	"
5D 22-27	"	82.2	3.3	"	"
5D 35-38	"	96.4	0.9	very well	"
5D 42-45	"	83.6	3.2	"	"
5E 15-20	"	90.2	1.5	"	"
5E 20-38	"	87.3	5.0	"	"

5F 6-12	"	89.3	3.3	"	"
5F 20-27	"	88.6	2.2	"	"
5F 51-55	Alluvium	91.0	1.0	very well	sym
5G 3-9	"	86.7	1.2	"	"
5G 20-25	"	91.3	2.9	"	"
5G 28-33	"	88.0	3.1	"	"
5G 44-49	"	93.2	1.9	"	"
5H 7-15	"	95.0	0.9	"	"
5H 29-34	"	86.7	4.9	"	"
5H 43-48	"	92.8	2.8	"	"
Core 6					
6A 20-25	Loess	29.2	10.0	well	"
6B 17-23	"	32.9	17.4	"	"
6C 5-10	Alluvium	16.1	26.3	"	"
6C 36-42	Alluvium	6.5	43.8	moderate	very +
6D 10-15	"	96.8	0.2	very well	sym
6D 30-35	"	90.0	3.9	"	"
6D 40-45	"	96.2	0.4	"	"
6E 10-15	"	93.3	1.6	"	"
6E 20-26	"	86.1	4.1	"	"
6E 40-45	"	31.2	20.1	mod. well	"
6F 4-8	"	36.4	19.9	"	"
6F 9-14	"	39.5	20.1	"	"
6F 35-40	"	11.9	53.5	"	"
6F 45-50	"	16.0	50.3	"	"
6G 10-17	"	22.8	35.8	"	"
6G 30-40	"	91.0	3.6	very well	mod -
6G 41-45	"	92.2	4.1	"	"

6G 52-55	"	99.3	0.0	"	"
6H 5-15	"	99.5	0.0	"	"
6H 25-30	"	36.9	16.5	mod. well	sym
6H 35-40	"	33.7	20.5	"	"
6H 55-60	"	37.8	17.6	"	"
6I 2-6	"	26.9	34.3	"	"
6I 12-18	"	35.9	38.0	"	"
6I 18-25	"	25.2	43.4	"	"
6I 32-36	"	22.8	44.2	"	"
6J 10-15	"	22.4	46.9	"	"
6J 35-40	"	27.7	45.0	"	"
6K 0-10	"	41.4	19.0	"	"
6K 20-25	Alluvium	37.8	20.0	mod.well	sym
6K 35-40	"	40.9	21.1	"	"
6K 50-60	"	36.9	10.4	well	"
6L 3-9	"	35.4	11.6	"	"
6L 29-34	"	35.8	17.9	"	"
6L 50-60	"	35.8	15.3	"	"
6M 0-10	"	34.2	11.3	"	"
6M 25-30	"	33.9	12.6	"	"
6M 39-44	"	37.7	11.8	"	"
6M 47-52	"	32.8	20.6	mod.well	"
6N 0-30	"	98.2	0.0	very well	"
6N 49-55	"	22.3	26.0	mod.well	"
6O 0-15	"	89.3	1.0	very well	"
6O 29-40	"	71.5	10.0	well	"
Core 7					
7D 8-13	"	8.7	16.1	well	"

7E 3-8	"	0.7	39.8	"	"
7E 22-26	"	39.7	0.2	"	"
7F 6-14	"	42.6	3.2	"	"
7F 38-46	"	48.7	1.0	"	"
7G 4-14	"	15.8	11.9	"	"
7G 29-37	"	21.9	36.3	mod.well	"
7H 8-14	"	10.3	47.8	"	"
7H 17-28	"	8.5	52.6	"	"
7I 4-12	"	43.8	4.0	"	"
7I 16-20	"	56.4	0.0	"	"
7I 29-36	"	40.8	2.8	"	"
7J	"	33.4	30.5	moderate	"
7K 0-18	"	49.5	16.7	"	"
7K 22-30	"	36.5	3.8	mod.well	"
7L 39-47	"	43.9	0.6	well	"
7M 12-19	"	2.3	9.1	very well	"
7N	"	40.1	30.4	poor	very +
7O	"	35.5	28.3	moderate	sym
7P	"	29.9	20.0	"	"
7Q	"	36.9	12.9	mod.well	"
7R	"	42.6	21.6	moderate	"
Core 8					
8B 24-29	Alluvium	35.8	26.6	mod.well	sym
8B 36-44	"	36.4	29.4	"	"
8C 2-6	"	27.8	30.8	"	"
8C 17-22	"	23.7	31.7	"	"
8D 24-32	"	37.8	2.7	"	"
8D 40-45	"	36.5	13.9	"	"
8E 10-15	"	35.4	12.9	"	"

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
8F 7-17	Alluvium	89.6	1.2	well	sym
8F 35-44	"	91.7	1.9	very well	"
8G 0-5	"	93.8	0.9	"	"
8G 32-38	"	21.3	41.9	moderate	very -
8G 48-52	"	22.6	42.3	"	sym
8H 15-20	"	19.5	47.8	"	"
8H 45-52	"	39.4	28.8	"	"
8I 10-15	"	15.4	50.2	mod. well	"
8I 40-45	"	16.9	39.8	"	"
8J 0-5	"	38.6	11.9	"	"
8J 30-35	"	37.2	10.3	"	"
8J 40-45	"	6.9	51.4	"	"
8J 50-60	"	5.2	40.9	"	"
8K 5-10	"	15.4	37.4	"	"
8K 20-25	"	20.6	35.6	"	"
8K 45-50	"	11.4	39.4	"	"
8L 5-10	"	9.0	46.4	well	"
8L 20-30	"	8.8	45.9	"	"
8L 50-55	"	6.2	51.2	"	"
8M 15-20	"	5.4	48.8	mod. well	"
8M 44-50	"	11.6	47.0	"	"

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
ML-5	till	16.7	32.6	moderate	mod -
MB-7	"	27.1	13.7	mod. well	mod -
MB-8	"	67.6	2.3	mod. well	mod -
MB-9	"	27.5	28.6	poor	very -
MB-10	"	63.8	10.7	moderate	mod -
MB-11	"	67.9	13.2	mod. well	mod -
MB-12a	"	60.9	15.8	moderate	mod -
MB-12b	"	72.2	2.7	moderate	mod -
MB-13c	washed till	91.4	0.2	mod. well	very -
MB-13c	till	73.5	5.2	moderate	mod -
MB-13d	washed till	89.6	0.5	mod. well	very -
MB-13d	till	70.4	6.9	moderate	mod -
MB-17a	till	90.0	3.6	moderate	mod -
MB-17b	till	71.3	9.6	moderate	mod -
MB-17c	till	62.8	13.4	moderate	very -
MB-17d	till(1)	73.5	10.3	moderate	mod -
MB-17d	till(2)	77.3	8.2	mod. well	very -
MB-17e	till	57.6	16.7	moderate	mod -
MB-17f	till	78.3	5.6	moderate	mod -
MB-17g	till	81.2	3.5	moderate	mod -
E-20	till	13.6	37.3	moderate	mod -
R-22	till	15.8	33.6	moderate	mod -
R-23	till	12.7	38.5	moderate	mod -
R-24	till(1)	12.7	35.6	poor	mod -
R-24	till 2)	9.6	54.3	moderate	mod -
IR-26	till	13.8	29.5	poor	mod -
IR-28	till(1)	11.9	27.5	poor	mod -
IR-28	till(2)	27.8	10.7	poor	mod -
IR-28	till(3)	11.7	27.3	moderate	mod -
IR-28	till(4)	10.8	49.6	moderate	mod -

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
IR-28	till(5)	20.7	21.6	moderate	mod -
IR-29	till	15.1	10.1	moderate	mod -
IR-31	till(1)	55.9	13.8	moderate	mod -
IR-31	till(2)	52.8	16.3	moderate	mod -
IR-31	till(3)	17.7	29.5	moderate	mod -
IR-31	till(4)	17.2	27.6	moderate	mod -
R033	till	15.7	28.0	moderate	mod -
R-36	till	12.0	45.4	moderate	mod -
IR-37b	till	17.2	13.9	moderate	mod -
W-47a	till(1)	21.0	29.6	moderate	mod -
W-47a	till(2)	10.3	43.9	moderate	mod -
W-47b	till(1)	14.4	21.3	moderate	mod -
W-47b	till(2)	15.8	28.8	moderate	mod -
W-52	till(1)	18.2	41.6	moderate	mod -
W-52	till(2)	15.6	41.9	moderate	mod -
W-53	till(1)	35.6	15.9	moderate	mod -
W-53	till(2)	21.0	19.7	moderate	mod -
W-53	till(3)	10.2	60.3	mod. well	mod -
W-53	till(4)	11.3	35.2	moderate	mod -
W-53	till(5)	6.9	72.4	mod. well	mod -
W-54	till(1)	11.3	35.2	mod. well	mod -
W-54	till(2)	10.6	52.7	mod. well	mod -
W-55	till	21.0	36.0	mod. well	mod -
IR-57	till	11.8	32.5	moderate	mod -
WH-62	till	12.5	63.3	moderate	mod -
WH-63	till	14.2	62.2	moderate	mod -
WH-73	till	16.7	61.5	mod. well	sym
OF-74	till	8.3	63.7	mod. well	mod -
OF-75	till	10.6	60.2	moderate	mod -
MR-78	till	12.3	42.3	moderate	mod -
CC-80	till	12.0	31.6	moderate	mod -
CC-81	till	27.1	20.5	moderate	mod -

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
CC-82	till	11.6	45.5	moderate	mod -
CC-83	till	12.9	50.6	moderate	mod -
W-114a	till	11.6	50.1	moderate	mod -
BH-120	till	8.6	7.9	moderate	mod -
BH-121	till	12.8	6.9	moderate	mod -
BH-122a	till(1)	39.4	6.6	moderate	mod -
BH-122a	till(2)	17.3	32.2	moderate	mod -
BH-122a	till(3)	18.9	30.8	moderate	mod -
LP-128	till	16.4	8.9	moderate	mod -
LP-129	till	17.4	29.8	moderate	mod -
LP-130	till	13.7	36.5	moderate	mod -
BH-136	till	19.0	21.2	moderate	mod -
LP-143	till	20.3	29.6	moderate	very -
T-149a	till	21.2	28.7	moderate	mod -
T-152	till	17.1	25.4	moderate	mod -
T-158	till	18.2	23.9	moderate	mod -
SP-161	till	12.3	10.8	moderate	mod -
SP-162	till	13.6	13.6	moderate	mod -
OR-165b	till	22.2	21.4	moderate	mod -
OR-168	till	7.3	17.2	moderate	mod -
MB-175	till	13.2	40.4	moderate	mod -
CC-185d	washed till	41.2	9.6	mod. well	very -
CC-185	till	12.8	32.7	moderate	mod -
PK-186a	till	13.2	33.8	moderate	mod -
PK-186b	till	15.7	41.2	moderate	mod -
PK-186c	till	12.7	40.3	moderate	mod -
PK-186d	till	9.9	50.1	moderate	mod -
PK-189d	washed till	35.2	12.7	mod. well	very -
PK-189d	till	16.3	32.6	moderate	mod -
PK-196	till	10.7	35.4	moderate	mod -

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
OR-201a	till	19.3	29.7	moderate	mod -
OR-201b	till	15.2	32.6	moderate	mod -
OR-201c	till	14.3	33.7	moderate	mod -
OR-201d	till	16.7	38.4	moderate	mod -
OR-201e	till	18.2	39.6	moderate	mod -
OR-201f	till	15.5	38.7	moderate	mod -
OR-208	till	15.7	41.2	moderate	mod -
MB-220	till	11.7	27.3	moderate	mod -
MB-221	till	10.9	48.6	moderate	mod -
MB-222	till	16.3	22.5	moderate	mod -
EK-229e	washed till	33.6	10.9	mod. well	very -
EK-230b	washed till	35.2	11.8	mod. well	very -
EK-230b	till	26.3	27.4	moderate	mod -
MB-232	till	9.7	48.2	moderate	mod -
GV-238	till	17.2	23.3	moderate	mod -
WH-243	till	9.9	26.0	moderate	mod -
JD-279	till	10.5	25.8	moderate	mod -
R-24	fluvial	69.5	1.0	well	sym
E-35a	fluvial	62.7	2.3	well	sym
E-35b	fluvial	73.5	4.2	well	sym
E-35d	fluvial	72.8	1.6	well	sym
E-35f	fluvial	75.6	2.8	well	sym
CC-80	fluvial	83.4	1.0	well	sym
B-182	fluvial	69.2	1.1	well	mod +
B-183a	fluvial	87.2	3.9	well	sym
B-183b	fluvial	65.1	6.5	well	sym
ML-6	lacustrine	10.0	13.4	well	mod +
MB-10	lacustrine	19.6	53.7	mod. well	mod +
MB-11	lacustrine	13.7	60.8	mod. well	mod +
MB-11	lacustrine	12.2	71.3	well	mod +
MB-11	lacustrine	29.4	23.8	moderate	mod +
MB-11	lacustrine	23.6	33.7	moderate	mod +

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
MB-11	lacustrine	20.2	36.9	mod. well	mod +
MB-11	lacustrine	27.3	20.8	moderate	mod -
MB-11	lacustrine	16.3	53.9	mod. well	mod +
MB-11	lacustrine	16.2	49.4	mod. well	mod +
MB-12a	lacustrine	13.6	54.7	mod. well	mod +
MB-13a	beach	61.3	2.7	mod. well	sym
MB-13b	lacustrine	19.8	42.9	moderate	mod -
MB-117e	lacustrine	16.9	48.2	mod. well	mod +
ML-18c	lacustrine	15.2	51.3	mod. well	mod +
E-34	beach	75.2	0.0	moderate	very -
WH-66	lacustrine	27.3	1.3	mod. well	sym
WH-67	lacustrine	23.8	2.5	mod. well	sym
WH-67	beach	76.3	0.2	very well	mod -
WH-68	lacustrine	24.6	2.0	mod well	sym
WH-69a	beach	88.3	0.0	very well	mod -
WH-69b	beach	46.2	5.3	poor	mod -
WH-69b	lacustrine	37.2	12.8	mod. well	sym
WH-69d	lacustrine	49.6	0.4	well	mod +
CC-86c	beach	79.2	0.3	mod. well	mod -
CC-87d	washed lacustrine	42.7	12.8	mod. well	mod -
CC-87h	washed lacustrine	40.6	10.3	mod. well	mod -
PL-103g	beach	82.6	1.3	very well	sym
BH-135b	lacustrine	12.8	41.6	mod. well	mod +
BH-136	lacustrine	15.7	22.9	mod. well	mod +
T-151e	lacustrine	17.6	37.6	moderate	mod +
T-151f	lacustrine	18.2	19.5	moderate	mod +
OR-165b	lacustrine	16.4	32.8	moderate	mod +
MB-171a	beach	86.5	2.2	mod. well	mod -
MB-171b	beach	79.4	6.5	mod. well	mod -
MB-171e	beach	89.3	1.0	very well	sym
MB-172c	washed lacustrine	41.7	0.3	mod. well	mod -

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
MB-172f	washed lacustrine	50.6	2.2	mod. well	mod -
MB-172g	washed lacustrine	52.7	0.0	mod. well	mod -
MB-173a	washed lacustrine	40.9	1.3	mod. well	mod -
MB-173c	washed lacustrine	37.6	0.2	mod. well	mod -
MB-176d	beach	82.3	1.1	mod. well	mod -
MB-176i	beach	69.4	3.6	mod. well	mod -
MB-176j	beach	90.0	1.0	mod. well	mod -
MB-176m	beach	74.2	2.7	mod. well	mod -
CC-180a	beach	72.6	4.9	mod. well	mod -
CC-184b	beach	76.3	8.8	mod. well	mod -
CC-184x	beach	86.4	1.7	mod. well	mod -
PK-192a	lacustrine	29.4	33.6	mod. well	mod +
PK-192b	lacustrine	20.7	39.4	mod. well	mod +
PK-192c	lacustrine	19.6	41.0	mod. well	sym
PK-197	lacustrine	23.6	48.2	moderate	mod +
PK-199i	beach	83.8	1.1	very well	sym
WH-233b	lacustrine	53.9	20.0	moderate	mod -
WH-233d	lacustrine	42.8	17.5	mod. well	mod +
WH-233i	lacustrine	50.0	15.6	mod. well	sym
WH-233j	washed lacustrine	75.6	1.3	mod. well	mod -
WH-235b	lacustrine	48.2	15.9	mod. well	sym
WH-243	lacustrine	62.8	3.6	mod. well	mod -
IR-38	loess	14.2	4.3	very well	sum
IR-39c	loess	11.2	6.8	very well	mod -
W-44a	loess	20.4	0.2	well	sym
W-45	loess	16.3	0.4	well	sym
W-46	loess	10.5	4.3	well	sym
W-47b	loess	7.5	2.1	very well	sym
W-48a	loess	7.8	5.0	very well	sym
W-48e	loess	7.4	2.2	very well	sym
W-48g	loess	11.2	7.3	very well	sym

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Sample	Sediment	Sand	Clay	Sorting*	Skewness**
IR-56c	loess	4.4	9.8	very well	sym
PL-88a	loess	7.6	2.9	very well	sym
PL-88b	loess	13.7	3.2	well	sym
PL-88c	loess	10.4	3.6	well	sym
PL-88d	cryoturbated loess	22.3	2.6	poor	mod +
PL-88e	loess	9.7	3.8	well	sym
PL-88f	loess	15.2	3.2	very well	sym
PL-98	loess	16.2	2.1	well	sym
PL-97a	loess	15.4	4.7	well	sym
PL-97b	loess	15.4	6.9	well	sym
PL-97c	cryotburated loess	33.5	6.9	poor	mod +
PL-97d	loess	14.9	4.6	very well	sym
PL-97e	loess	18.2	2.2	very well	sym
PL-97f	cryotburated loess	45.2	2.9	moderate	mod +
PL-97g	loess	14.0	1.8	very well	sym
PL-97h	loess	15.7	3.9	very well	sym
PL-97i	loess	16.2	2.0	very well	sym
PL-97j	loess	15.9	2.6	well	sym
PL-101g	cryotburated loess	22.7	8.3	poor	mod +
MH-119	loess	19.8	1.7	well	sym
BH-122a	loess	19.7	2.3	well	sym
PL-261	loess	13.4	1.3	very well	sym
MI-268	loess	11.9	4.9	very well	sym
E-1	tephra	3.6	1.7	very well	sym
E-1b	tephra	0.7	0.1	very well	sym
MB-11	tephra	3.1	4.0	very well	sym
MB-16ca	tephra	6.7	3.9	very well	mod -
MB-16cb	tephra	5.0	6.9	very well	mod -
MB-16cc	tephra	2.1	11.0	very well	mod -
W-50	tephra	1.3	2.4	very well	sym

Sample	Sediment	Sand	Clay	Sorting*	Skewness**
T-149	tephra	6.2	3.6	very well	sym
MI-268	tephra	8.4	4.0	very well	mod +

* Scale from Folk and Ward, 1957.

** Adapted from Folk and Ward, 1957:

Absolute Skewness values 0.50 - very
0.2-0.50 - moderate (mod)
0.0-0.2 - symmetrical (sym)
positive or negative skewness indicated by postscript.

APPENDIX E: Mineralogical Analyses

I. Heavy Mineral Analyses

The proportions of mafic minerals and minerals with specific gravity greater than 2.65 are given as percentages. Amounts less than 1% are given as "trace" (designated by "t").

N.B. The term "grossularite" is applied to all garnets which are white to buff in colour. "Almandine" refers to all red-brown garnets, while "Andradite" is used for greenish yellow or greenish brown garnets. Although this nomenclative scheme is subject to some inaccuracy, it is employed here as an aid in distinguishing the observable physical differences present in the garnets of the region's sediments. Definite identification of the garnet species would require individual analysis of each mineral grain, a process beyond the scope of this study.

E-1-cores	Olivine	Zircon	Sphene	Almandine	Andradite	Grossularite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutile	Xenotime	Pyrite	Apatite	Fluorite
1B 35-40	t	2	6		t	10	2	3	t	t	t	9	2	t	t	t	4	t	2	13	t	1	t	t	3			5	17	t	2	t	2		5	10
IC 22-29		1	4	t		11	t	2	t	t	t	13	2	t	t	1	3		2	14		2	t	t	3		t	5	17	1	2	t	1		6	8
ID 12-18		1	6		t	12	t	2	t	t	t	12	1	t	t	1	3	t	2	15		1	t	t	3			4	14	1	2	t	2		6	10
IF-6-11		1	5			12	t	2	t		t	13	1	t	t	1	3		2	15	t	1	t	t	3	t		4	17	1	2	t	1		5	10
IF 27-32		t	4		t	14	t	t	t	t	t	11	1	t	t	1	5		4	23		1	t	t	2			3	12	t	1	t	2	t	5	10
IG 17-23		1	4	t	t	15	t	t	t	t		10	1	t	1	1	4		3	27		1	t	t	2	t	t	3	10	t	2	t	2		4	9
IG 35-40	t	t	2		t	15		t	t		t	10	1	t	1	1	5	t	4	30	t	1	t	t	2	y		2	9	t	1	t	2		3	10
IH 12-14		1	3		t	14	t	t	t			7	t	t	t	t	4		3	29	t	2		t	4			4	18	t	t		2		5	10
IH 23-27		1	5		2	14	t		t			6		t		t	3		4	30		1	t	t	3			3	15		2		t		2	11
II 0-10	t	1	3		1	13	t	t	t	t		8	1	t	t	1	4		3	26	t	2	t	t	3	t		2	11	t	2	t	1		4	12
II 21-30		t	2		2	15		1	t	t		6	t	t	1	1	4	t	3	27	t	2	t	t	2	t	t	2	10	1	2	t	1	t	6	10
IK 12-20		t	1	t	t	17	t	t	t			8	1	t	t	1	4		4	30	t	2	t	t	2			3	11	t	1	t	2		3	10
IL 35-40		t	1	t	t	16	t	t	t			8	1	t	t	1	4	t	5	35		1	t	t	2	t		1	9	1	1	t	2		3	10
IM comp	t	2	2		2	12		t			t	6		t	t	t	5		4	33	t	2	t	t	2			1	9	t	1	t	1		4	14
2B 15-20		2	2		t	13	t	3	t		t	6	t	t	t	1	3	t	3	30	1	5	2	2	2			2	9	t	t	t	2		6	1
2E 9-16		2	2		t	14		1	t		t	5	1	1	t	t	t	t	3	30	2	4	2	1	2			2	10	t	t	t	2		3	8
2F 6-12		1	2		t	13	t	1	t		1	5	t	1	1	t	4	t	4	35	2	3	1	1	2			2	9	1	t	t	2	t	3	8
2G 8-12	t	1	1	t		15	t	1	t	t	1	5	t	1	t	t	4	t	5	35	2	3	t	1	2	1		2	8		t	t	1		3	8
2H 22-26		1	1		t	15	t	1	t		t	5	1	1	t	t	4		4	33	2	2	t	1	2			1	9	1	t	t	1		3	8
2H 48-60	t	2	1	t	t	12	t	t	t			5	t	t	1	1	4		3	32	2	3	t	1	2		t	2	9	t	1	t	t		5	11
2I 0-30		2	t	t	t	12	t	1	t	t		5	t	t	1	1	4		4	32	1	2	t	1	3	t		1	9	t	2	1	1		4	11
2K 19-28	t	1	1		t	14		t	t			5	t	t	t	t	3	t	5	35	1	3	1	1	2	t		2	9	t	1	t	2		3	8
2L 36-43	t	1	t	t	t	16		t	t		t	5	t	t	t	t	3	1	7	40	t	2	t	1	2	t		1	8	t	t	t	1		3	6
3C 38-48		1	1		t	15	t	2	t	t		3	t	1	t	1	5		3	26	2	3	t	t	3		t	1	11	t	2	t	1		4	13
3D 21-27		2	1	t	t	15	t	2	t		1	6	t	1	t	t	4	t	5	27	2	3	t	1	1	t	t	2	10		t	t	2		3	10
3D 45-52	t	1	3		t	12	t	1		t		8	t	t	t	t	5		1	30	t	3	t	2	2	t	t	2	12		1	t	1		6	11
3D 60-72		2	2		t	12	t	t	t			6	t	t	t	1	3		1	28	1	2	t	1	3		t	2	14	t	2		1	t	6	12

	Olivine	Zircon	Sphene	Almandine	Andradite	Grossularite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutite	Xenotime	Pyrite	Apatite	Fluorite
4D 5-10		1	1		t	15		1				6	1	t	t	1	2		4	34	t	2	1	t	1	t	t	3	9		1	t	1	t	3	11
4D 22-29		1	1	t	t	15	t	t		t		5	1	1	t	1	2		3	33	2	2	t	t	2		t	3	10		t	t	t	t	3	12
4D 40-46		1	1	1	1	15	1	1	t		t	4	t	1	t	1	2	t	3	33	t	4	1	1	2	t	t	3	10	t	t	t	1		3	8
4E 14-21		1	1	t	t	16	t	t				5		1	t	1	3		4	35	t	2	1	t	2		t	3	10	t	1	t	t		4	8
4E 42-50		t	t	t	t	16	t	1	t		t	4		t	t	1	1		5	37	2	4	t	t	2	t	t	4	8	1	2	t	t		4	9
4F 20-27		1	1	t	2	15	t	1	t		t	4		t	t	t	2	t	3	35	t	3	t	1	2		t	3	10	1	1	t	1		3	10
4G 10-15	t	1	2	t	1	14	t	2	1	t	t	4	t	1	t	t	2	t	5	35	t	3	t	1	2		t	3	10	t	1	t	t	t	2	9
4G 45-50		1	1		t	15	t	2	t	t		4	t	t	t	1	5		3	26	2	3	t	t	3		t	1	11	t	2	t	1		4	13
4H 20-26		1	1	t	t	15	t	1	1		t	4		1	t	1	2	t	5	35	1	3	t	t	3		t	3	10		t	t	t		3	9
4H 48-53	t	2	1		t	16	t	2				4	t	t	t	1	3	t	4	35	t	1	t	t	2	t	t	4	10	t	t	t	t		3	10
4I 12-16		1	2		1	14	t	2	1	t	t	4	t	1	t	t	2	t	5	35	t	3	t	1	2		t	3	10	t	1	t	t		2	9
4I 37-44		1	1	t	t	16	t	1	t		t	4		t	t	1	2	t	6	33	1	3	t	t	2	t	t	4	10	t	1	t	t		2	10
4J 1-7		t	1	t	t	14	t	1	t		t	4	t	t	t	1	2	t	6	37	2	4	t	t	2		t	4	11	t	1	t	t		2	9
4J 31-40	t	1	1	t	1	15	t	2	t	t	t	4	t	t	1	1	1	t	4	33	1	3	t	t	2		t	4	9	1	1	t	t	t	3	10
4K 0-20		1	4	t	t	15	t	t	t	t		10	1	t	1	1	4		3	27		1	t	t	2	t	t	2	10	t	2	t	2		4	9
4K 26-32		2	1	t	1	12	t					5	t	t	t	1	3		3	31	t	2	1	1	2		t	5	13	t	2	t	t		3	10
4K 36-42		t	t	t	t	16	t	1	t		t	4		t	t	1	1		5	37	2	4	t	t	2	t	t	4	8	1	2	t	t		3	10
4K 55-60		2	2		t	12	t	t	t			6	t	t	t	1	3		1	28	1	2	t	1	3		t	2	14	t	2		1	t	6	12
4L 0-15		1	1	t	t	15						5	t	t	t	2	3		4	31	1	2	1	1	1	t	t	3	10	t	1	t	2	t	3	10
4L 30-40		2	t	t	t	14	t	1	t			5	t	t	t	1	3		4	33	t	3	1	t	1		t	3	10	1	1	t	2		3	9

	Olivine	Zircon	Sphene	Almandine	Andradite	Grossularite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutite	Xenotime	Pyrite	Apatite	Fluorite
5C 25-38		1	2	t	t	15	t	t	t	t		5	t	t	t	1	2		4	34	2	2	t	1	1		t	4	10	t	t	t	1		3	10
5C 48-52		1	1		t	17	t	t	t			6	t	t	t	t	4		6	29	5	3	t	1	4		t	2	9		t	t	1		4	10
5D 45-52		1	1	t	2	15	t	t		t		7		t	t	t	3		4	34	2	2	t	2	4		t	1	10		1	t	1		5	9
5E 15-20		1	1		1	14	t	t	t	t	t	6	t	t	t	t	3		5	25	t	2	t	3	3	t	t	2	9	t	2	t	2		5	13
5E 20-38		1	1		1	16	t	t	t	t		6		t	t	t	4		6	31	3	2	t	2	4		t	1	9	t	2	t	[illegible]		4	10
5F 6-12	t	2	1		3	15	t	1	t			5	t	t	t	t	4		4	30	t	2	1	t	3		t	4	12	1	3	t	1		3	9
5F 20-27		1	1		1	16	t	t	t	t		5	t	t	t	t	5	t	2	36	2	2	t	2	4		t	2	10		t	t	1		3	11
5F 45-60		1	1	t	2	15		t		t		5	t	t	t	t	5		7	32	1	3	t	1	4	t	t	2	8		2	t	1	t	3	11
5G 3-9		1	1		3	14	t	t	t		t	6	t	t	t	t	4	t	4	32	4	3	t	1	4		t	1	9		2	t	1		4	10
5G 28-33		1	1	t	t	15	t		t			5	t	t	t	2	3		4	31	1	2	1	1	1	t	t	3	10	t	1	t	2	t	3	10
5H 7-15	t	1	1	t	t	12	t	t	t	t		5	t	1	t	1	3	t	3	30	1	2	1	t	2		t	4	12	1	3	t	1		3	9
5H 29-34		2	1		3	15	t	1	t			5	t	t	t	t	4		4	30	t	2	1	1	2		t	3	10	t	2	t	t	t	3	10
5I comp		1	1	t	2	13	t	t	t	t	t	5	t	1	t	t	2		4	35	1	2	1	t	2	t	t	3	10	t	1	t	1		3	10
6B 23-28		1	1	t	t	15						5	t	t	t	2	3		4	31	1	2	1	1	1	t		3	10	t	1	t	2	t	3	10
6C 36-42		1	1		t	15	t	t	t			8	2	2	1	1	5		4	30	t	1	1	1	1			2	9	t	1	t	2		2	10
6D 10-15		1	1		t	14	t	t	t	1	t	6	t	t	t	t	3		5	25	t	2	t	3	3	t		2	9	t	2	t	3		5	12
6D 45-50		1	1	t	t	14	t	t	t	1		5	t	t	t	1	3	t	3	26	1	3	1	1	3			2	8	t	3	1	3	t	4	12
6E 20-30		2	t	t	t	14	t	1	t			5	t	t	t	1	3		4	33	t	3	1	t	1		t	3	10	1	1	t	2		3	9
6F 4-9		1	t	t	2	15	t	t	t	t		6	t	t	t	1	3		5	25	t	2	1	1	3			2	10	t	2	t	1		4	11
6F 45-50		2	t	t	t	14	t	1	t			5	t	1	t	1	3		4	33	1	2	1	1	1			3	10	1	1	t	2		4	10
6G 30-40	t	2	1		t	15	t	2	t	t		5	t	t	t	t	3		4	34	t	2	1	t	2			2	9	t	2	t	t	t	3	11
6H 0-10		1	1	t	t	15		1				6	1	t	t	1	2		4	34	t	2	1	t	1	t	t	3	9		1	t	1	t	3	11
6H 55-60		2	1		t	11		t				5	t	1	t	t	3	t	2	32	t	2	1	2	2	t		5	15	t	2	t	t		2	9
6I 18-25		1	1		t	13	t	t	t			5	t	t	t	t	3		4	30	t	2	1	1	3			2	14	t	2	t	2		4	11
6J 35-40		1	1		t	14	t	t	t	t		4	t	1	t	t	3	t	3	29	1	2	t	3	3		t	3	12	1	2	t	1		3	11
6K 0-10		1	1	t	t	16	t	1	t			5	t	1	t	1	3		3	35	t	1	1	t	1	t		2	9	1	1	t	1		3	10
6K 50-60	t	2	t	t	t	14	t	t	t			5	t	t	t	1	3		4	33	1	2	1	1	1			3	10	1	1	t	2		3	9

	Olivine	Zircon	Sphene	Almandine	Andradite	Grossularite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutite	Xenotime	Pyrite	Apatite	Fluorite
6L 29-34		1	2			15		t	t	t		5	t	t	t	1	2		5	35	t	2	1	t	1		t	4	10	t	t	t	1		3	10
6L 50-60		2	1		t	13	t	t				5	t	1	t	t	3		3	30	1	2	1	t	2			4	12	1	3	t	1		3	9
6M 0-10		2	1		t	15	t	1	t	t		6	t	t	t	1	3		3	31	t	3	1	t	2			4	10	1	2	t	1		4	9
6N 0-30		1	t		2	14	t	t	t			5	t	t	t	t	3		5	30	t	3	2	t	5	t		3	10	t	2	1	t		4	10
6O 30-37		1	1		1	15	t	t				5	t	1	t	1	3		4	35	t	2	1	t	2		t	3	10	t	1	t	t		4	8
6P comp		2	1		1	14	t	1				6	1	t	t	1	3		4	36	t	1	t	t	1		t	2	11	1	2	t	1		3	7
7E 3-8		2	1		1	14		t	t	t		5		1	t	1	3		3	30	1	3	t	t	3	t		3	10	t	3	t	t		3	11
7E 22-26		2	1	t	t	13	t	t				5	t	1	t	1	2	t	3	30	1	2	1	t	2			4	12	1	3	t	1		3	9
7F 38-46		2	1		t	15		1	t			5		1	t	1	3		3	31	t	3	1	t	2			4	10	1	2	t	t		3	10
7G 29-37		1	1		1	14	t	t				6	1	t	t	t	3		3	32	1	2	t	t	3			3	10	t	1	t	2		3	10
7H 14-20		1	1	t	t	16	t	t				5	t	1	t	1	3		4	35	t	2	1	t	2		t	3	10	t	1	t	t	t	4	8
7I 16-20		2	1		t	15	t	1				6		1	t	1	3	t	4	36	t	1	t	t	t	t	t	2	11	1	2	t	t		3	8
7J comp	t	1	1		1	14	t	t	t		t	6	1	t	t	t	3		4	31	1	2	1	1	1	t	t	3	10	t	1	t	2		3	10
7K 0-18		2	1		t	13		t	t	t		5	t	1	t	t	3		4	31	t	3	1	t	2			4	10	1	2	t	t		4	10
7L 33-40	t	2	t	t	t	16		t	t			3	t	2	t	1	2		4	35	t	2	t	t	2		t	3	10	t	1	t	1		3	10
7M 12-19		2	1		t	15		1	t	t		5	t	1	t	1	3		3	31	t	3	1	t	2			4	10	1	2	t	t		4	10
7N comp		1	t	t	2	15	t	t	t	t		6	t	t	t	t	3	t	5	25	1	2	1	1	3	t		2	10	t	2	t	1	t	4	15
7O comp		2	1	t	1	14		t	t	t		5	t	1	t	t	3	t	4	30	1	3	t	t	3	t		3	10	t	3	t	t		3	11
7P comp	t	1	t		2	14	1	t	t		t	6	t	1	t	t	3	t	5	26	1	2	1	1	4	t	t	2	9	t	2	t	2	t	4	12
7Q comp	t	1	t	t	3	14	t	t	t	t	t	6	t	t	t	t	3		4	26	2	2	t	1	4	t	t	3	10		1	t	2	t	4	12
7R comp	t	2	1	t	2	11	t	t	t	t	t	5	t	t	t	t	3	t	3	31	t	2	1	2	2	t	t	5	13	t	2	t	t		3	10
8B 24-29		3	1		1	10		t	t	t		4	t	1	t	t	2		2	30	t	2	1	2	2			6	15	t	4	1	t		3	8
8C 18-22		2	1		t	11		t	t			5	t	1	t	t	3	t	2	32	t	2	1	2	2	t		5	15	t	2	t	t		3	9
8D 24-32		2	1		1	13		t	t		t	4	t	t	t	t	3		3	31	t	3	1	1	2			6	13	t	2	t	t		3	9
8D 40-45		2	2		2	14	t	t	t	t		5	t	1	t	t	3		1	30	4	2	1	t	4			4	11	t	t	t			3	12
8E 10-15		2	1	t	1	12	t	t	t	t		5	t	t	t	1	3		3	31	t	2	1	1	2			5	13	t	2	t	t		3	10
8F 7-17	t	2	2		2	14	t	t	t	t		5	t	1	t	t	3	t	4	29	2	2	2	t	3	t		3	10	t	1	t			4	11

	Olivine	Zircon	Sphene	Almandine	Andradite	Grossularite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutite	Xenotime	Pyrite	Apatite	Fluorite
8G 0-5		2	2		2	14	t	t			t	5	t	1	t	t	3		3	32	t	2	1	1	3			3	9	t	2	t			3	12
8G 45-52		1	t		3	14	t	t	t			6	t	t	t	t	3		4	26	2	2	t	1	5		t	2	10	t	1	t	2		4	12
8H 45-55		2	1		t	13						4		t	t	1	3		3	31	t	3	1	1	2			6	13	t	2	t	t		3	9
8J 10-15		1	1		t	15		1	t			4	t	t	t	2	3	t	4	35	t	1	1	t	2			4	10		1	t	t	t	4	9
8K 25-30	t	2	1		t	16	t	2				4	t	t	t	1	3	t	4	35	t	1	t	t	2	t		4	10	t	t	t	t		3	10
8L 20-30		2	t	t	t	14	t	1	t			5	t	t	t	1	3		4	33	t	3	1	t	1		t	3	10	1	1	t	2		3	9
8M 40-44		1	1		t	15		2				4		t	t	1	2		6	39	1	1	t	t	1			3	9	t	t	t	t		4	8
ML-5till		1	3	t	2	13	1	2	1	t		5	1	t	t	t	2		2	30	3	3	1	1	3			4	10	t	1	t	t		1	8
MB-8till		1	1		1	14	t	1	t		t	4	t	t	1	1	3		6	27	2	2	1	2	3	t		3	11		2	t	t		4	11
MB-10till		2	1		1	12	t	t		t		3	t	t	t	1	3	t	3	30	2	2	1	2	3			5	12	t	2	t	t		4	9
MB-11till		2	1		t	14	1	1	t			4	t	t	t	1	3	t	4	33	2	2	t	1	2	t	t	4	10	t	t	t	t		3	9
R-24 till 1		2	t	t	t	14	t	1	t			5	t	t	t	1	3		4	33	t	3	1	t	3		t	2	9		1	t	1		3	10
R-24 till 2		3	t	t	1	12	t	1	t	t		4	t	t	1	1	3		3	32	1	3	1	1	3	t	t	2	10		1	t	t		3	10
IR-28till 1		2	t		2	13	t	t	t			3	t	t	t	t	3		3	33	1	2	t	1	2			3	10	t	1	1	1		4	15
IR-28till 2		2	t		t	14	t	t	t			4	t	t	t	t	3		3	32	2	2	t	1	2	t		2	11		1	t	t		6	14
IR-28till 3		t	4		4	10	t	t		t		6	t	t	t	t	3		4	22	2	3	2	2	2	t		3	12	t	2	t	1		3	12
IR-28till 4	t	3	t	t	1	12	t	1	t	t		3	t	1	t	t	5		2	30	3	2	1	2	4	t		3	9		2	t	t	t	3	9
IR-28till 5		t	4		4	10	t	t				5	t	1	t	t	3		4	22	2	3	2	2	2	t		1	13	t	1	t	t		4	14
IR-31till 1		t	t		2	15	1	t	t			4	t	t	t	t	3		4	31	t	2	1	t	1			4	15		2	t	t		6	10
IR-31till 2		t	t		2	14	2	t			t	5	t	t	t	t	4		4	30	2	3	1	2	4			4	12	t	2	t	t		2	7
IR-31till 3	t	t	t		t	14	t	t	t	t		6	t	t	t	t	3	t	3	27	2	3	t	2	4	t		4	13		3	t	t		5	10
IR-31till 4		t	t	t	2	12	1	t		t		6	t	t	t	t	3	t	4	25	2	4	2	1	2	t	t	2	17		2	t	t	t	3	12
W-44a loess		t	t		t	5	t	t	t			1	t	t	t	t	2		5	30	3	26	10	2	t			1	7		1	t			1	7
W-47b loess		t	2		t	4	t	t	t	t		t	t	t	t	t	2		6	30	3	25	10	3	t	t		2	8		t	t	t		2	5
W-47btill 1		t	t		3	10	1	t	t		t	4	t	t	t	t	3	t	4	31	t	2	t	1	t			3	11	t	2	t	t	t	6	12
W-47btill 2	t	t	1		1	12	t	t	t	t		4	t	t	t	t	3	1	3	30	2	t	t	1	t			2	11		2	1	t		7	14

	Olivine	Zircon	Sphene	Almandine	Andradite	Grossu'arite	Vesuvianite	Andalusite	Kyanite	Sillimanite	Staurolite	Epidote	Cordierite	Tourmaline	Orthopyroxene	Clinopyroxene	Wollastonite	Cummingtonite	Actinolite	Hornblende	Hastingsite	Biotite	Phlogopite	Muscovite	Chlorite	Corundum	Hematite	Ilmenite	Magnetite	Ulvospinel	Chromite	Rutite	Xenotime	Pyrite	Apatite	Fluorite
W-53till 1		t	t		2	15	1	t	t			4	t	t	t	t	3	t	3	31	1	2	1	t	3			2	13		2	t	t		6	11
W-53till 2		2	t		t	14	t	t			t	4	t	t	t	t	3		3	32	3	2	t	t	2	t		2	11		1	t	t		6	13
W-53till 3		2	3		2	15	t	1	t	t		5	1	1	1	1	3		3	30	2	5	1	1	2	t	t	1	9		1	t	t		3	8
W-53till 4	t	2	4	t	3	12	1	t	t			4	t	t	t	t	2		4	29	3	3	1	2	3	t	t	2	12	t	1	1	1		3	7
W-53till 5		2	3		2	15	t	1	t	t		5	1	1	1	1	3		2	30	3	5	2	1	2	t	t	1	9		1	t	t		3	8
WH62till		1	2		2	14	1	1	t		t	3	1	1	1	1	4	t	4	26	3	3	t	t	3	t		2	12	t	2	t	t		2	8
CC80till		t	1		1	12	t	t		t		4	t	t	t	t	3		5	26	4	3	t	1	2		t	3	11		1	t	t		6	15
PL88bloess		t	t	t	1	6	t	1	t			2	t	t	1	1	2		6	29	3	2	t	t		t		3	17		3	1	t		8	14
PL95loess		t	t		2	7	t	t	t	t		1	t	t	t	2	2		5	29	5	2	t	1	t	t		4	15		4	2	t	t	7	12
BH122atill 1		1	1		3	10	t	t	t			3	t	t	t	1	3	t	6	26	3	2	t	2	2	t		3	13	t	2	t	t		6	12
BH122atill 2		t	1	t	2	12	t	t			t	5	t	t	t	1	3		4	32	2	2	t	1	4	t		4	12		3	t	t		3	10
BH122atill 3	t	t	1	t	1	12	t	t	t	t		4	t	t	t	t	3	t	4	29	3	2	t	t	3	t		2	11	t	2	1	2	t	6	13
BH136 till		1	1		t	15	1	t	t			6	1	t	t	1	2		4	34	t	2	t	t	2	t	t	3	9		1	t	1		4	10
T 152 till		2	6		t	10	2	3	t	t		9	1	1	1	t	3		2	22	1	1	1	t	2	t		2	12		t	t	2		5	10
T 158 till		2	2		2	15	t	1	t	t	t	5	1	1	1	2	3		3	30	3	4	1	1	3	t	t	1	9		1	t	t		3	8
O RL65btill		2	4	t	3	12	1	t	t			4	t	t	t	t	2		4	29	3	3	1	2	3	t		2	12	t	1	2	1	t	3	7
MB222till		1	t		3	14	t	t	t			6	t	t	t	t	3		4	27	1	2	1	1	3		t	2	10	t	2	t	1		4	12
GV 238till		1	4		2	16	t	1	t	t		4	t	1	t	t	3		3	26	1	2	1	1	4			2	14	t	2	t	t		3	12
WH243till		t	1		2	12	t	1	t			3	1	1	t	t	3	t	4	32	2	2	1	1	3	t		4	12		3	t	t	t	3	10
PL261loess		t	t	t	1	3	t	t	t		t	t	t	t	1	2	2		6	29	5	3	t	1	t			6	16	t	4	t	t		6	15
MI268loess		t	t		t	4	t	t	t	t		t	t	t	t	t	2		6	27	4	22	11	6	t	t		1	6		2	t	t		2	7
JD279till		1	3		2	15	1	1	t			4	1	1	1	1	4		4	26	2	3	1	1	1	t	t	2	12		2	t	t		2	8

II Major Mineral Analyses

The proportions of each mineral are given as percentages. Amounts less than 1% are given as trace (designated by "t").

Qtz....Quartz
Felds..Feldspar
CO_3....Carbonate
Hblde..Hornblende
Gnt....Garnet
Mgn....Magnetite
Fl.....Fluorite
Px.....Pyroxene

TILL

Sample	Qtz	Felds	CO_3	Hblde	Gnt	Mgn	Fl	Px
MB-7	42	35	8	6	4	3	2	t
MB-8	50	16	5	11	7	5	5	1
MB-9	40	50	2	4	2	1	1	t
MB-10	70	10	1	8	4	4	3	t
MB-11	65	12	2	8	5	4	3	1
MB-12b	80	10	t	6	3	2	t	t
MB-17b	70	12	t	8	5	2	3	t
MB-17c	72	10	t	9	6	2	1	t
MB-17d1	76	11	t	7	3	2	1	1
MB-17d2	73	16	t	5	2	1	2	t
MB-17e	68	14	t	8	4	3	2	1
MB-17f	69	12	t	9	3	4	3	1
MB-17g	65	15	1	6	4	4	3	1
R-24-1	50	25	3	10	5	3	3	1
R-24-2	45	20	4	15	6	5	5	1
IR-26	50	30	6	10	1	2	1	t
IR-28-1	50	30	8	6	1	2	3	t
IR-28-3	50	30	8	6	2	3	3	t
IR-28-4	40	40	10	6	2	2	1	t
IR-28-5	50	30	8	6	2	3	3	t
IR-29	45	40	2	9	2	1	2	t
IR-31-1	45	35	6	6	3	3	2	t
IR-31-2	50	30	11	5	2	2	1	t
IR-31-3	60	22	2	7	4	3	2	t
IR-31-4	50	33	4	6	2	3	2	t
R-33	45	25	4	16	3	3	3	1
R-36	40	30	5	10	6	4	4	t
IR-37b	45	35	3	7	4	3	2	t

Sample	Qtz	Felds	CO_3	Hblde	Gnt	Mgn	Fl	Px
W-47a1	45	25	15	8	3	3	1	t
W-47a2	40	33	10	8	4	3	2	t
W-47b1	40	33	12	7	2	3	3	t
W-47b2	40	30	13	8	3	3	3	t
W-52-1	40	28	6	12	6	5	3	t
W-52-2	40	35	6	10	4	3	2	t
W-53-1	55	20	11	6	3	3	2	t
W-53-2	55	20	12	6	3	3	1	t
W-53-3	50	25	5	10	5	3	2	t
W-53-4	40	35	10	7	3	3	2	t
W-53-5	50	24	6	10	5	3	2	t
W-54-1	45	23	5	14	7	4	2	1
W-54-2	33	30	14	10	6	4	2	1
W-55	40	32	10	9	4	4	1	t
IR-57	40	30	13	10	2	2	3	t
WH-62	40	40	10	5	2	2	1	t
WH-63	40	40	10	5	3	1	t	t
WH-73	50	30	10	4	3	2	1	t
OF-74	40	40	5	9	2	3	1	t
OF-75	35	40	5	9	6	4	2	t
MR-78	40	40	2	11	3	5	t	t
CC-80	45	25	12	7	3	3	4	t
CC-81	45	25	10	8	4	2	5	t
CC-82	50	30	14	3	1	1	1	t
CC-83	40	40	10	6	2	1	2	t
W-114a	45	30	5	10	5	3	2	1
BH-120	45	35	5	9	4	1	1	t
BH-121	50	30	6	9	3	1	1	t
BH-122a1	50	30	8	5	2	3	2	t

Sample	Qtz	Felds	CO_3	Hblde	Gnt	Mgn	Fl	Px
BH-122a2	40	32	12	8	3	3	2	t
BH-122a	40	30	14	7	3	3	3	t
BH-136	40	30	8	11	5	3	3	t
T-152	45	35	9	5	2	2	2	t
T-158	45	30	6	9	3	3	3	1
SP-161	50	30	7	9	2	2	t	t
SP-162	45	35	7	9	1	2	1	t
OR-165b	45	35	5	7	3	3	2	t
OR-168	45	35	4	8	4	3	1	t
MB-175	45	35	6	7	3	3	1	t
PK-186a	50	37	4	5	2	1	1	t
PK-186b	50	40	2	6	3	1	t	t
PK-186c	45	35	4	9	4	2	1	t
PK-186d	55	35	3	4	2	1	1	t
PK-195	50	35	9	4	1	1	t	t
PK-196	50	37	8	3	2	t	t	t
OR-201a	45	30	9	8	4	2	2	t
OR-201b	50	35	15	1	1	t	t	t
OR-201c	50	30	10	4	2	3	2	t
OR-201d	40	33	13	7	3	2	1	t
OR-201c	50	25	10	6	5	3	2	t
OR-201f	40	32	12	8	4	2	2	t
OR-208	45	37	2	6	5	4	1	t
MB-220	45	35	6	7	3	3	t	t
MB-221	40	50	2	3	2	1	2	t
MB-222	40	40	8	4	2	2	2	t
MB-232	45	35	17	2	t	t	t	t
GV-238	35	35	12	7	4	4	3	t
WH-243	40	30	14	8	3	3	2	t
JD-279	40	30	12	7	4	3	2	1

COLLUVIUM

Sample	Quartz	Feldspar	Heavy Minerals
ML-5	82	12	6
ML-18a	75	15	10
ML-18b	72	18	10
ML-18c	63	21	16
ML-18d	54	27	19
ML-18f	64	24	12
ML-18h	70	18	12
ML-18j	58	30	12
LP-142a	70	15	14
LP-142c	60	24	16

LOESS

Sample	Qtz	Felds	CO_3	Hblde	Gnt	Mgn	Fl	Px
IR-38	71	3	6	16	3	t	1	t
IR-39c	72	8	2	12	4	2	2	-
W-44a	88	2	2	6	1	1	t	-
W-45	91	2	1	5	1	1	t	-
W-46	84	3	5	7	t	1	-	-
W-47b	80	5	4	6	2	1	2	-
W-48a	78	5	2	10	3	1	1	-
W-48e	66	8	3	17	3	2	1	-
W-48g	85	4	2	6	2	1	t	-
IR-56c	75	6	4	12	3	1	t	-
PL-88b	72	4	2	11	2	5	4	t
PL-88e	92	2	0	4	1	t	t	-
PL-95	76	4	1	10	2	4	3	-
PL-97d	75	2	1	16	3	2	1	-
PL-97g	80	8	2	7	2	1	t	t
PL-97h	89	3	3	4	2	t	-	-
PL-97j	85	3	2	8	1	1	1	t
PL-101g	83	5	1	9	2	1	t	-
MH-119	66	12	2	9	1	4	3	t
BH-122a	70	14	2	9	1	3	1	t
PL-261	74	10	2	8	1	3	3	t
MI-268	85	8	0	6	t	1	1	t

APPENDIX F: Chittick Analysis

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
El Core Samples				
1B 20-25 cm	Alluvium	11.7	6.2	1.89
1B 45-48 cm	"	12.2	6.9	1.77
1C 13-16	"	11.5	7.4	1.55
1C 42-45	"	14.8	9.2	1.61
1D 12-15	"	14.6	7.9	1.85
1D 43-48	"	13.0	9.6	1.35
1E 8-12	"	12.9	8.0	1.61
1F 14-19	"	10.0	2.6	3.85
1G 4-10	"	15.1	9.3	1.62
1G 44-52	"	21.6	10.8	2.00
1H 20-25	"	11.9	6.4	1.86
1J 32-34	"	13.2	9.3	1.42
1K 12-20	"	13.8	7.2	1.92
1K 34-37	"	14.4	6.3	2.29
1L 5-10	"	13.3	6.8	1.96
1L 37-44	"	10.3	5.6	1.84
1M 10-15	"	12.5	9.8	1.28
2B 5-10	Ah soil horizon	18.7	9.0	2.08
2B 45-50	Alluvium	12.7	7.2	1.76
2C 0-12	"	3.0	2.7	1.11
2C 20-25	"	18.0	11.5	1.57
2D 0-18	Cca soil horizon	42.1	23.6	1.78
2E 8-17	Alluvium	9.1	5.2	1.75
2E 33-39	Ah soil horizon	9.3	6.2	1.50
2E 46-52	Alluvium	17.0	13.3	1.28
2F 6-15	"	18.3	12.3	1.49
2F 25-32	"	7.9	4.2	1.88
2G 8-12	Alluvium	12.3	6.9	1.78
2G 15-22	"	17.0	13.0	1.31
2H 3-11	"	8.3	5.3	1.57
2H 17-22	"	8.0	5.0	1.60
2H 50-60	"	4.2	2.9	1.45

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
2J 15-22	Alluvium	6.8	4.4	1.55
2J 35-44	"	13.6	8.2	1.66
2K 19-28	"	8.6	5.0	1.72
2K 38-44	Cca Soil Horizon	39.8	27.4	1.45
2K 46-50	Ah Soil Horizon	12.1	8.3	1.46
2L 3-15	Alluvium	16.7	8.9	1.88
2L 30-34	"	17.3	11.2	1.54
2L 44-50	"	15.9	9.9	1.61
3B 0-15	Ah Soil Horizon	14.4	10.9	1.32
3C 5-11	Alluvium	20.7	9.6	2.16
3C 38-48	"	3.9	2.9	1.34
3D 13-18	"	11.8	9.1	1.30
3D 40-43	"	12.6	9.8	1.29
4D 5-10	Bt Soil Horizon	16.7	9.0	1.86
4D 22-29	Alluvium	20.8	9.1	2.29
4D 40-46	"	9.8	5.1	1.92
4E 14-21	"	11.3	5.6	2.02
4E 33-39	"	15.1	11.2	1.34
4F 0-4	Cca Soil Horizon	40.2	25.0	1.61
4F 20-27	Alluvium	13.6	7.2	1.89
4F 41-48	"	14.8	10.3	1.44
4G 10-15	"	12.5	9.6	1.30
4G 33-36	"	24.7	19.4	1.27
4G 45-50	"	12.8	7.3	1.75
4H 20-26	"	10.7	6.6	1.62
4H 48-53	"	8.2	4.9	1.67
4I 12-16	"	7.4	5.0	1.49
4I 33-36	"	10.1	6.6	1.53
4I 45-52	"	11.2	7.5	1.49
4J 1-5	"	15.2	11.1	1.37
4J 12-20	"	13.2	7.9	1.67
4J 26-31	"	7.7	4.3	1.79
4J 40-44	"	3.9	3.0	1.30
4K 0-15	"	5.6	4.4	1.27
4K 26-32	"	2.0	0.7	2.86

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
4K 44-50	Alluvium	3.8	2.9	1.31
4L 1-8	"	10.1	8.8	1.15
4L 11-18	"	18.1	16.0	1.13
4L 32-36	"	22.7	18.2	1.25
5C 15-22	"	13.7	8.7	1.56
5C 25-33	"	4.9	2.9	1.69
5C 48-52	"	6.8	4.5	1.51
5D 15-19	"	4.9	2.8	1.75
5D 35-39	"	4.0	2.3	1.74
5E 15-20	"	6.9	4.1	1.68
5F 6-12	"	12.8	8.9	1.44
5F 20-27	"	I3.9	9.5	1.46
5F 51-55	"	2.6	1.6	1.63
5G 3-9	"	6.8	4.2	1.62
5G 20-25	"	9.7	5.9	1.64
5G 44-49	"	6.8	4.2	1.62
5H 7-15	"	14.7	8.8	1.67
5H 29-34	"	13.7	8.2	1.67
6A 20-25	Ah Soil Horizon	7.6	4.2	1.81
6B 17-23	"	8.1	4.9	1.65
6C 5-10	Alluvium	7.7	4.2	1.83
6C 36-42	"	12.9	8.0	1.61
6D 10-15	"	11.3	7.5	1.51
6D 30-35	"	8.8	5.2	1.69
6E 10-15	"	8.7	5.6	1.55
6E 20-26	"	9.4	5.9	1.59
6E 40-45	"	10.7	6.2	1.73
6F 4-8	"	12.7	8.0	1.59
6F 9-14	"	12.9	8.1	1.59
6F 17-23	"	25.9	15.5	1.67
6F 45-50	"	13.3	7.2	1.85
6G 10-17	"	15.4	9.4	1.64
6G 30-40	"	9.2	5.8	1.59
6G 52-55	"	9.1	5.2	1.75
6H 5-15	"	8.9	4.8	1.85

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
6H 25-30	Alluvium	12.8	8.5	1.51
6H 55-60	"	13.0	8.8	1.48
6I 2-6	"	12.7	8.4	1.52
6I 18-25	"	12.9	8.3	1.55
6I 32-36	"	14.1	8.0	1.76
6J 10-15	"	15.0	9.6	1.56
6J 35-40	Ah Soil Horizon	8.7	4.9	1.78
6K 0-10	Alluvium	11.9	5.8	2.05
6K 20-25	"	12.1	7.3	1.66
6K 50-60	"	13.3	6.9	1.93
6L 3-9	"	12.9	6.8	1.90
6L 29-34	"	13.5	7.5	1.80
6L 50-60	"	13.1	7.3	1.79
6M 0-10	"	14.2	8.5	1.67
6M 25-30	"	16.8	12.0	1.40
6M 39-44	"	16.2	11.7	1.38
6N 0-5	"	11.3	6.6	1.71
6N 49-55	"	12.1	7.0	1.73
6O 0-10	"	10.8	9.7	1.11
6O 29-36	"	11.2	7.5	1.49
7D 8-13	"	11.3	7.5	1.51
7E 3-8	"	9.5	6.4	1.48
7E 22-25	"	9.2	5.9	1.56
7F 6-14	Ah Soil Horizon	8.1	3.9	2.08
7F 38-46	Alluvium	7.9	4.7	1.68
7G 4-11	"	10.1	6.1	1.66
7G 29-37	"	10.3	5.3	1.94
7H 8-14	"	11.2	6.7	1.67
7H 17-22	"	14.9	7.7	1.94
7I 4-12	"	6.2	3.7	1.68
7I 29-36	"	7.9	4.3	1.84
7J Composite	"	12.0	8.8	1.36
7K 22-30	"	7.9	3.9	2.03
7L 39-47	"	6.5	3.8	1.71
7M 12-19	"	15.4	9.0	1.71

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
7N Composite	Alluvium	14.7	9.3	1.58
7O Composite	"	14.0	9.2	1.52
7P Composite	"	15.8	7.9	2.00
7Q Composite	"	14.9	8.8	1.69
7R Composite	"	16.7	8.9	1.88
8B 24-29	"	12.4	6.9	1.80
8B 36-44	"	14.1	7.6	1.86
8C 2-6	"	13.2	8.7	1.52
8C 17-22	"	14.1	7.7	1.83
8D 24-32	"	14.8	8.7	1.70
8D 40-45	"	14.9	7.9	1.89
8E 10-15	"	19.0	10.6	1.79
8F 7-13	"	18.8	9.9	1.90
8F 35-44	"	16.7	8.6	1.94
8G 0-5	"	15.2	8.5	1.79
8G 32-38	Ah Soil Horizon	14.7	7.9	1.86
8G 48-52	Alluvium	14.9	7.9	1.89
8H 15-20	"	14.2	7.8	1.82
8H 45-52	"	13.8	7.7	1.79
8I 10-15	"	13.5	7.8	1.73
8I 40-45	"	14.0	7.4	1.89
8J 0-5	"	13.7	7.5	1.83
8J 30-35	"	14.3	7.7	1.86
8J 50-55	"	14.2	7.3	1.95
8K 5-10	"	13.4	7.7	1.74
8K 20-25	"	13.7	7.8	1.76
8K 45-50	"	12.4	6.9	1.80
8L 5-10	"	12.4	6.8	1.82
8L 20-25	"	8.4	5.2	1.62
8L 50-55	"	8.8	5.1	1.73
8M 15-20	"	8.6	4.9	1.76
8M 44-50	"	8.9	5.2	1.71
ML-5	Till	13.5	9.2	1.47
MB-7	"	17.9	13.3	1.35

Location	Sediment Type	%Calcite	%Dolomite	Calcite/ Dolomite
MB-10	Till	18.0	14.1	1.28
R-21	"	15.8	10.7	1.48
IR-28	"	16.3	12.0	1.36
W-44	"	29.0	26.9	1.08
IR-57	"	9.9	8.6	1.15
WH-62	"	13.9	7.9	1.76
WH-63	"	10.7	6.8	1.57
WH-70	"	14.9	9.3	1.60
OF-75	"	13.4	8.0	1.68
OF-76	"	10.1	7.6	1.33
MR-78	"	13.9	9.8	1.42
CC-80	"	15.3	10.6	1.44
BH-121	"	12.3	8.8	1.40
BH-122a	"	15.3	10.7	1.43
LP-129	"	16.7	11.4	1.46
OR-167i	"	14.7	10.0	1.47
PK-186b	"	11.9	7.3	1.63
PK-195	"	16.3	11.2	1.46
OR-206f	"	9.4	6.6	1.42
WH-241	"	20.7	9.9	2.09
MR-250a	"	14.7	10.3	1.43
SP-264	"	10.6	6.1	1.74

APPENDIX G: List of Sample Locations

Station	Location*	Sediment Type	Investigations Conducted
E1	NE-19-8-2	cfv (i)	cdikmpstvy
E2 a-j	NE-19-8-2	cf (i)	fst
E3	12-14-8-3	bce	lt
E4	4-24-8-3	bc	bt
ML-5	8-21-7-3	b;ct(i);a	bklsv
ML-6	6-7-7-3	l	mps
MB-7	11-28-6-4	t	ksw
MB-8	7-10-6-5	t	s
MB9	4-31-5-5	t	s
MB10	1-24-5-6	tvls	dkms
MB11	14-13-5-6	tgvl	dmsv
MB12 ab	NW-18-5-5	tgl	dfms
MB13 ad	S-21-5-5	l	dst
MB14 ae	36-4-5	l	gt
MB15 a-r	W-5-4	bv	bv
MB16 a-d	35-4-4	bfv	fsv
MB17 a-g	Se-5-6	tgl	dmst
ML18 a-k	Sw-7-3	t	ls
E19	8-35-8-3	t	s
E20	S-1-9-3	tf	fs
R21	13-14-9-3	tf	fks
R22	4-25-9-3	tlf	dfs
R23	13-1-10-3	bta	as
R24	13-18-10-2	bgtf	sw
R25 a-j	(1,12)-11-3	bf	bf
IR26	4-30-11-2	t	sw
IR27 a-i	E-11-3	bvt	bvs
IR28	4-23-11-3	t	ksw
IR29	4-27-11-3	t	sw
IR30	10-18-11-3	tgt	fs
IR31	2-14-11-4	btgt	fsw
R32	14-3-10-3	tf	fs
R33	14-9-9-3	t	sw

Station	Location*	Sediment Type	Investigations Conducted
E34	10-18-8-3	bvl	btv
E35a-f	(23,24)-8-3	bf	gt
R36	1-30-9-2	tf	s
IR37 ab	NW-22-11-2	t	sw
IR38	5-25-11-2	ta	as
IR39 a-d	1-12-2	fa	af
IR40	5-17-12-1	tf	f
W41 a-e	(17,20)-11-1	bfa	bt
W42 a-d	(21,2B)-11-1	bf	bt
W43 a-c	(22,27)-11-1	fa	ast
W44 ab	NW-2-12-1	a	aks
W45	7-10-12-1	tca	as
W46	7-36-11-1	a	as
W47 ab	SE-1-12-1	ta	asw
W48 a-j	CE-11-1	a	as
W49	8-34-10-1	tf	fs
W50	11-36-10-1	fv(i)	fsv
W51 a-e	CE-10-1	gtf	fs
W52	7-1-10-1	t	sw
W53	6-23-9-1	gtl	dfmsw
W54	13-34-9-1	tgl	dfmsw
W55	12-21-10-1	t	sw
IR-56 abc	(13,24)-10-2	btla	admsw
IR57	13-31-10-1	bt	ksw
ML58	13-5-6-2	t	sw
ML59	16-36-5-3	cf(i)	t
ML60	16-13-5-3	b	b
WH61	13-20-4-2	tg	s
WH62	5-5-4-2	t	ksw
WH63	9-31-2-2	bt	ksw
WH64	12-17-2-2	gt	fs
WH65	8-6-2-2	g	fs
WH66	6-18-1-2	l	dms
WH67	13-11-1-2	l	dms
WH68	12-18-1-1	l	dms

Station	Location*	Sediment Type	Investigations Conducted
WH69 a-d	(25,36)-1-2	lg	dfms
WH70	14-23-1-3	t	ksw
WH71	6-27-1-3	t	sw
WH72	14-21-1-3	g	fs
WH73	14-36-1-4	t	sw
OF74	1-18-2-4	t	sw
OF75	6-12-2-5	t	ksw
OF76	2-11-2-5	bt	ks
MR77	4-29-1-5	tf	fs
MR78	13-4-1-5	btg	ksw
MR79	2-3-2-6	b	bg
CC80	9-31-2-5	btgl	bdfsw
CC81	13-33-2-5	btf	s
CC82	1-26-2-6	t	s
CC83	1-22-2-6	t	s
CC84 a-k	(9,10) 3-6	bv	bgv
CC85	8-21-3-6	l	dt
CC86 a-g	24-3-7	bl	bdmst
CC87 a-h	(7,18,19)-4-6	l	dmst
PL88 a-f	NE-8-2	ba	as
PL89	1-25-8-2	bcg	g
PL90	1-20-8-1	s	csy
PL91	9-22-8-1	s	csy
PL92	10-14-8-1	s	csy
PL93	8-14-8-1	s	s
PL94	5-11-8-1	s	s
PL95	16-21-7-1	as	as
PL96	5-4-8-1	s	csy
PL97 a-j	NE-7-2	ba	as
PL98	14-10-8-3	s	csy
PL99	7-15-8-3	s	cs
PL100	8-15-8-3	s	csy
PL101 a-p	SW-8-3	bae	al
PL102	5-5-8-3	be	bl
PL103 a-g	SE-31-7-3	bv	v

Station	Location*	Sediment Type	Investigations Conducted
PL104	11-32-7-3	bv	v
PL105 a-m	NW-7-3	ea	als
FX106	5-25-6-3	b	b
FX 107	14-18-7-2	s	csy
PL108 a-e	NE-7-3	a	as
PL109	7-20-8-2	s	cs
E110 a-q	(13,14)-8-3	ea	al
PL111 a-u	CW-8-2	ea	al
PL112 a-hh	N-8-2;NW-SE-8-1	bea	alv
R113 a-f	(1-3)-9-2	t	lsw
W114 a-d	(24,25)-9-2	t;fv(i)	sv
W115	6-10-9-1	t	s
W116 a-d	NE-27-8-1	t	dsw
W117 a-b	SE-25-8-1	t	ls
W118	5-26-8-1	bv	btv
MH119	4-10-12-4	a	as
BH120	14-17-11-5	t	sw
BH121	5-4-11-5	t	ksw
BH122	NE-31-9-5	bgftca	adfiksw
BH123 a-d	S-18-10-5	bgta	afs
LP124	9-6-8-5	ct	sw
LP125	9-13-7-6	t	sw
MB126	5-16-6-5	l	t
MB127	1-28-6-5	l	t
LP128	8-33-7-5	t	s
LP129	6-10-8-5	t	ksw
LP130	10-21-8-5	tl	ds
LP131	13-32-8-5	t	s
T132	6-36-9-5	t	sw
T133	13-19-9-4	tl	dsw
BH134	4-14-9-5	t	sw
BH135 a-l	NW8-4, SW9-4	tl	dlsw
BH 136	13-28-8-4	tl(i)	dmsw
BH137	13-27-8-4	t	s
BH138	14-15-8-4	b	b

Station	Location*	Sediment Type	Investigations Conducted
BH139	7-9-8-4	bv	v
ML140	9-11-8-4	cf	fs
ML-141 a-h	24,35-7-4	bvl	tv
LP142 a-c	SW-34-7-4	t	lsw
LP143	14-23-7-5	t	s
E144 a-d	(30,31)-8-2	t	lsw
T145	1-25-10-4	tl	dmsw
T146	12-31-9-3	t	s
T147	5-19-9-3	t	sw
T148	16-12-9-4	tl	dsw
T149 a-c	29-8-3	t;fv(i);fc(i)	dlsvw
T150 ab	(30,31)-8-3	tl	lsw
T151 a-g	1-9-4	tl	lsw
T152	7-4-9-4	t	sw
T153	8-9-9-4	t	sw
T154	5-15-9-4	t	sw
T155	8-21-9-4	t	sw
T156 ab	NE-33-9-4	t	sw
T157	3-2-10-4	t	sw
T158	1-2-10-4	t	sw
SP 159	6-28-10-6	t	sw
SP160	14-34-10-7	tf	s
SP161	14-10-10-7	bta	asw
SP162	4-5-10-7	tla	adsw
SP163	4-30-9-7	tla	ads
SP164 a-c	(17,18)-8-7	tl	sw
OR165 a-c	24-7-8	tla	adisw
OR166	11-20-7-7	w	dm
OR167 a-g	SE-6-7	l	dkst
OR168	5-30-6-6	t	sw
LP169 a-c	(25,36)-7-7	ta	as
SP170	13-31-9-6	ta	sw
MB171 a-k	SW-6-5	l	st
MB 172 a-l	E-5-5	l	dst
MB173 a-h	(4,9,16)-5-6	l	t

Station	Location*	Sediment Type	Investigations Conducted
MB174 a-f	(3,4)-5-5	l	dt
MB175	13-22-4-5	t	sw
MB176 a-m	NE-4-6	l	t
MB177 a-c	13-4-6	l	t
MB178 a-f	SE-4-6	l	t
CC179 a-d	(26,27)-3-6	l	t
CC180 a-f	(19-22)-3-6	l	t
CC181 a-g	SW-4-6	l	t
B182	11-25-3-4	fv(i)	fsv
B183 ab	NE-20-3-3	bvf	fv
CC184 a-f	(26-28)-3-7	bl	bt
CC185 a-g	N-3-7	l	dmst
PK186 ad	(18-20)-3-8	tl	dkstw
PK187	10-30-2-8	l	g
PK188 ag	N-3-8	l	dst
PK189 af	SE-4-8	la	dst
PK190 ac	W-4-7	l	t
PK191 a-h	NW-4-8	lf	dfmst
PK192 a-d	(23,24)-4-9	l	dt
PK193 a-g	NE-4-9	l	t
PK194	12-13-5-9	w	dm
PK195	8-23-5-9	tg	fks
PK196	13-24-5-9	tl	dst
PK197	3-1-6-9	l	dst
PK198 a-j	SW-6-8	l	t
PK199 a-k	NW-5-7	la	adst
OR200 a-i	E-5-7	la	adst
OR201 a-f	(10,11)-6-7	tl	dmst
OR202 a-f	15-6-7	l	t
OR203	1-20-6-6	l	t
OR204	4-8-6-6	l	t
OR205	9-14-6-6	l	t
OR206 a-f	SW-6-6	la	akst
MB207 a-e	NE-5-6	l	t
OR208	3-3-7-7	ta	as

Station	Location*	Sediment Type	Investigations Conducted
FW209	14-10-8-30-W3	ba	ab
FW210	15-36-7-30-W3	ba	ab
FW211	5-31-7-28-W3	bv	v
FW212	1-19-7-28-W3	bv	v
FW213 a-g	4-8-7-28-W3	bv	bv
BC214	9-27-6-29-W3	ba	as
BC215	1-9-6-29-W3	ta	as
FW216	15-9-8-27-W3	ba	as
FW217	12-12-8-28-W3	ba	a
FW218	5-17-8-28-W3	ba	a
MC219	14-32-9-27-W3	t	s
MB220	4-11-7-4	tf	fs
MB221	14-36-6-4	t	sw
MB222	1-4-7-4	tf	fsw
ML223	13-22-6-3	f	fs
ML224 ah	NE-6-3	bce	l
ML225 at	SE-7-3	bcea	al[illegible]
EK226 ag	N-5-9	l	t
EK227 ac	18-5-9	l	t
EK228 ac	5-5-9	l	t
EK229 ae	NW-4-9	l	t
EK230 ab	10-4-9	l	t
EK231 ac	2-4-9	l	t
MB232	14-13-6-5	t	s
WH233 aj	NW-1-2	l	t
WH234 ae	(12;13)-1-2	l	t
WH235 a-h	(18-20)-1-1	l	t
GV236	9-15-3-30-W3	t	sw
GV237	4-28-2-29-W3	t;fv(i);l	dsvw
GV238	6-17-2-30-W3	t	sw
JD239	10-21-2-1	t	sw
JD240	13-16-2-1	w	dm
JD241	2-7-2-1	t	ks
WH242	8-6-2-1	w	dm
WH243	5-3-1-2	tl	dsw

Station	Location*	Sediment Type	Investigations Conducted
WH244	8-21-3-2	w	dm
E245	14-34-8-3	tl	sw
PL246	13-20-8-1	w	dm
MR247 ab	23-2-10	b	b
MR248	6-10-2-10	b	b
PK249 a-c	18-3-8	w	dm
MR250 ab	28-2-7	tl	ks
MR251 ab	21-2-7	b	b
PK252	14-32-4-7	w	dm
E253	10-24-8-3	w	dm
FX254	15-23-6-3	bea	als
FX 255	13-23-7-3	be	bl
FX256 a-n	5E-7-1	bea	al
FX257 a-h	NW-6-2	bta	al
FX258	9-27-5-1	t	s
FX259	10-22-6-1	t	s
FX260 af	N-33-6-1	cea	als
PL261	9-24-7-2	a	as
PL262	6-34-8-2	bc	s
SP263	16-14-7-9	f	g
SP264	8-28-8-8	tf	fks
MI265	13-19-12-1	fa	af
MI266	11-36-12-2	fa	af
MI267	5-35-12-2	fa	af
MI268	8-29-12-2	clv(i)	asv
MI269	16-27-12-3	fa	af
MI270	4-27-12-1	fa	af
MI271	6-35-12-1	fa	af
MI272	6-2-13-1	fa	af
MI273	15-5-13-1	fla	at
MI274	12-15-13-1	la	at
MI275	SE-26-13-1	w	dm
FX276a-bb	S-7-2;NE-6-2	bea	als
JD277	16-18-5-1	t	s
JD278	3-11-5-1	fv(i)	fsv
JD279	9-14-4-1	t	sw

Station	Location*	Sediment Type	Investigations Conducted
CC-280 a-c	6-3-5	f	t
CC-281 a-d	6-3-4	f	t

Notes for Appendix G

*All locations West of the 4th Meridian, unless otherwise specified.

Sediment Type

a - aeolian

b - bedrock

c - colluvium

e - glacial erratics

f - fluvial

g - glaciofluvial

l - lacustrine

s - soil; profile description

t - till

v - volcanic ash discrete from bedrock

w - sample from water body

(i) - interbedding of sediments

Investigations

a - aeolian transport direction

b - bedrock analysis

c - soil chemistry

d - diatom analysis

f - fluvial current direction

g - areal geomorphology

i - insect analysis

k - chittick analysis

l - limits of glaciation

m - mollusc analysis

p - polynology

s - sediment texture and mineralogy

t - terrace and lake level delineation

v - volcanic ash analysis

w - till fabric analysis

y - phytolith analysis

APPENDIX H: Selected Section Descriptions

ML-5 8-21-7-3-W4

Depth	Sediment Type
0 - 186 cm	Loess; 7.5 YR 4/3 m (Dark Brown); sandy silt; contains small amount of carbonate; structureless; stands in steep slopes.
186 - 353 cm	Till and Colluvium; 7.5 YR 4/2 m (Dark Brown); clayey silt; carbonate content approximately 20%; no structure or jointing; stands in near-vertical cliffs; cohesive; stone content 3%, increasing near base; stones 95% local, 5% Canadian Shield granite and gneiss.
353 - 371 cm	Till and Colluvium; 7.5 YR 4/2 m (Dark Brown); silt; carbonate content approximately 20%; no structure or jointing; stands in near vertical cliffs; cohesive; stone content 10%; stones 85% local, 15% Canadian Shield granite, gneiss, and basalt.
371 cm - base	Ravenscrag formation - weak sandstone interbedded with thin bands of bentonite, grey clay, and red clay.

MB-10 1-24-5-6-W4

0 - 82 cm	Brown Chernozemic soil profile, consisting of Ah, Btj, BC, Cca horizons. See soil profile descriptions, Appendix I.
82 - 235 cm	Lacustrine clay; 7.5 YR 5/2 m (Brown); weak varves, 2-4 mm thick, sandy partings between couplets, no colour difference; no truncation of varves or sand lenses noted; horizontal bedding throughout; stands in vertical cliffs; cohesive; stone content less than 1%; some vertical disruption of varves beneath stones. Within lacustrine clay, irregular thin pockets of volcanic ash, 7.5 YR 8/1 m (White); shards weathered intensely; 92% silt; structureless; appears to be derived from bedrock.
235 - 800 +	Till, 7.5 YR 6/4 m (Light Brown); silty sand, carbonate content varies between 15% and 35%; no structure; badly slumped, slope angle 35°; non-cohesive; stone content 30%; stones 15-20% local, 65% Canadian Shield granites, gneisses, and basalts, 15% Palaeozoic carbonates, 2% Athabasca sandstone; matrix 50-60% Canadian Shield material; clast orientations random; till extends to base of section.

Depth	Sediment Type
MB-11	14-13-5-6-W4
0 - 12 cm	Loess, 7.5 YR 5/1 m (Grey); silt; structureless; gradational lower contact.
12 - 763 cm	Lacustrine clay, 7.5 YR 5/2 m (Brown); weak varves, 2-4 mm thick, sandy partings between couplets, no colour difference; varves in irregular pods, pockets, and lenses, separated by unstratified clay; irregular sand lenses and flame-like structures; lower varves contorted; numerous slump and dewatering structures in lower portion of sequence; stone content less than 1%, distortion of varves below stones; cohesive; abrupt contact.
763 - 764 cm	Volcanic ash, 7.5 YR 8/1 m (White); silt; shards relatively fresh; structureless; abrupt contact.
764 - 855 cm	Lacustrine clay, as above.
855 - 963 cm	Fluvial sand, 7.5 YR 5/4 m (Brown); structureless; non-fossiliferous; abrupt contact.
963 - 1429 cm	Till, 7.5 YR 6/4 m (Light Brown); silty sand; structureless; stone content 25%; crystallines 65%, Palaeozoics 20%, locals 15%; fabric random; to base of section.
R-24	13-18-10-2-W4
0 - 0.64 m	Fluvial sand, 7.5 YR 6/4 m (Light Brown); interbeds of fluvial silt, 7.5 YR 6/4 m; structureless; non-cohesive; abrupt contact with underlying unit.
0.64 - 11 m	Till, 7.5 YR 6/5 m (Light Brown); clayey silt; weak columnar jointing; stands in near-vertical cliffs; stone content 2%; Canadian Shield material 40%, Palaeozoic carbonates 50%, local stones 10%, contains flame-like inclusions of underlying unit, modal 1.5 m in length, 30 cm thick; fabric 540°E.
11 - 17 m	Till, 2.5 YR 4/1 m; clay; structureless; stands in near vertical cliffs; stone content 5%; Canadian Shield material 60%, Palaeozoic carbonates 35%, local material 5%; contains thin lenses of quartzite-rich gravel in lower 2m; fabric S 35°E.
17 - 18 m	Glaciofluvial gravel, 7.5 YR 5/3 m (Brown); in discontinuous lenses up to 1.3 m thick; poorly-developed cross-stratification near base; quartzites 85%, other local material 5%, Canadian Shield crystallines 10%.

Depth	Sediment Type
18 - 34 m	Bearpaw Formation; shale and irregular sandstone beds and iron concretions; to base of section.
IR-28	4-23-11-3-W4
0 - 6.8 m	Till, 7.5 YR 6/5 m (Light Brown); silt; very strong columnar jointing; stands in vertical cliffs; stone content 3% Canadian Shield crystallines 45%, Palaeozoic sediments 40%, local 15%; fabric due S; gradational contact.
6.8 - 13.4 m	Till, 7.5 YR 6/4 m (Light Brown); sandy silt; weak columnar jointing; lenses of sand present; stone content 6%; ratio similar to above; fabric poor but approximately S; gradational contact.
13.4 - 13.9 m	Till, 7.5 YR 6/5 m (Light Brown); silt; columnar jointing; stands in vertical cliff; stone content 4%; abrupt lower contact.
13.9 - 17.1 m	Till, 7.5 YR 5/2 m (Brown); silty clay; structureless; cohesive; stands in vertical cliff; stone content 6%; Shield crystallines 50%; Palaeozoic carbonates 35%; local material 5%; gradational lower contact.
17.1 - 17.3 m	Till, 7.5 YR 6/4 m (Light Brown); silt; weak columnar jointing; stone content 8%; to base of section.
IR-31	2-14-11-4-W4
0 - 3.5 m	Till, 7.5 YR 6/6 m (Reddish-Brown); sand; several sand and silt interbeds and lenses; sand 7.5 YR 6/7 m (Reddish Brown), irregular crossbedding; silt 7.5 YR 6/2 m (Pinkish Grey), laminar bedding; stone content 40%; local 10%, Shield crystallines 45%, Palaeozoic 45%; random fabric; gradational lower contact.
3.5 - 5.7 m	Till, 7.5 YR 6/6 m (Reddish-Brown) and interbedded sand, 7.5 YR 6/7 m (Reddish Brown); till stone content 35%; local 45%, Shield Crystallines 30%, Palaeozoic 25%; till matrix sandy; fabric random; sand laminarly-bedded, minor contortions; heavy mineral suite resembles Oldman formation; current directions southerly; gradational lower contact.
5.7 - 6.6 m	Till, 2.5 YR 4/1 m (Dark Grey); silty; no structures or jointing; near-vertical face; stone content 1%; crude stratification in upper portion; sharp lower contact.
6.6 - 6.9 m	Bearpaw erratic; shale; extends entire length of section.

Depth	Sediment Type
6.9 m	Clay or till, 2.5 YR 4/1 m (Dark Grey); thickness 2 cm; 3 equally spaced parting lineations of very fine-grained sand; abrupt lower contact.
6.9 - 7.3 m	Sand, silt, and glaciofluvial gravel, 7.5 YR 6/6 m (Reddish-Brown); complex interbedding; contorted cross-bedding in medium-grained sand; contorted imbrication pattern in gravels; basal unit is 5 cm thick band of silt; gradational lower contact.
7.3 - 7.8 m	Till, 2.5 YR 4/1 m (Dark Grey); silty; no structures or jointing; near-vertical face; stone content 1%; several large Bearpaw shale erratics to 0.25 m thick noted; gradational lower contact.
7.8 - 11.2 m	Glaciofluvial sand, 7.5 YR 5/4 m (Brown), with interbedded thin silts, 2.5 YR 5/1 (Grey) and flame-shaped non-aligned inclusions of till, 2.5 YR 4/1 m (Dark Grey); bedding in sand and silt units is contorted; current directions generally southerly in uncontorted sections; till silty, strongly resembles overlying unit; single pebble present was Bearpaw Shale.
11.2 - 11.4 m	Till, 2.5 YR 4/1 m (Dark Grey); silty; no structures or jointing; stone content 1%.
11.4 - 14.6 m	Bearpaw Formation; shale; laminar bedding, slightly contorted in upper portion; to base of section.
W-47b	8-1-12-1-W4
0 - 77 cm	Loess, 7.5 YR 6/4 m (Light Brown); silt; contains small amount of carbonate; coarse, laminar bedding; stands in steep slopes.
77 - 312 cm	Till, 7.5 YR 6/6 m (Reddish-Brown); silt; irregular columnar jointing; semi-cohesive; stone content 5%; crystallines 45%, Palaeozoics 35%, locals 20%; 75% of Palaeozoics are dolomite; fabric poor, trends southerly; gradational contact.
312 - 418 cm	Till, 7.5 YR 6/5 m (Light Brown); silt; very strong columnar jointing; stands in vertical cliffs, stone content 3%; Canadian Shield crystallines 45%, Palaeozoic sediments 40%, local 15%; fabric S 5° E; to base of section.
W-53	6-23-9-1-W4
0 - 1 m	Sand, silt, clay, and marl, complexly interbedded; numerous truncations; sand laminarly bedded,

Depth	Sediment Type
	apparently lacustrine; marl fossiliferous, containing Pisidium sp. and ostracoda; some Pisidium in clay; contact gradational laterally and vertically.
1 - 2 m	Till, 7.5 YR 6/2 m (Pinkish Grey); sandy silt; structureless; non-cohesive; stone content 8%; crystallines 50%, Palaeozoics 45%, locals 5%; most of Palaeozoic clasts are limestones; fabric S 30° E, poor; gradational contact.
2 - 2.5 m	Till, 5 YR 4/1 m (Dark Grey); silt; structureless; stands in vertical faces; stone content 3%; ratios as above till; fabric S 35° E; abrupt contact.
2.5 - 6.8 m	Glaciofluvial gravel, 5 YR 7/8 m (Reddish yellow); many iron stains, few manganese dendrites; minor sand interbeds; crossbedding, festoon-bedding, imbrications, flame structures all indicate a north-easterly current; some collapse structures in sands; abrupt contact.
6.8 - 7.6 m	Till, 5 YR 5/3 m (Reddish Brown); clay; structureless; cohesive; stone content 3%; fabric S 60° E; abrupt contact.
7.6 - 8.9 m	Till, 7.5 YR 4/4 m (Dark Brown); silt; structureless; stands in vertical face; cohesive; stone content 5%, local 25%, crystallines 40%; Palaeozoics 35% (largely dolomite); fabric good, S 40° E, abrupt contact.
8.9 - 9.2 m	Till, 5 YR 5/3 m (Reddish Brown); clay; structureless; cohesive; stone content 2%; fabric S 60° E; abrupt contact.
9.2 - 15.3 m	Glaciofluvial sequence; interbedded sand, silt, and clay, with frequent gravel lenses; truncated beds common; deformed laminar and crossbedding, imbrication, festoons; modal current direction approximately south-southeast; non-fossiliferous; to base of section.
CC-80	9-31-2-5-W4
0 - 2 m	Lacustrine silt, 7.5 YR 5/2 m (Brown); structureless; cohesive; moderately sorted, no stones; contained fragments of ostracods and Pisidium sp.
2 - 3 m	Glaciofluvial gravel and sand, 7.5 YR 6/6 m (Reddish Brown); interbedding; imbrication indicates northwest current; abrupt upper and lower contacts.
3 - 11 m	Till, 7.5 YR 4/3 m (Dark Brown); silty; interbedded with irregular sand and silt lenses; poorly developed

Depth	Sediment Type
	laminar stratification; no jointing; cohesive; compacted; stone content 8%; crystallines 50%; Palaeozoics 30%, local 20%; fabric good, S 35° E.
11 - 12 m	Oldman erratic; sandstone.
12 - 15 m	Bearpaw Formation; shale; laminar bedding, slightly contorted in upper portion; to base of section.
BH-122a	15-31-9-5-W4
0 - 0.6 m	Loess, 7.5 YR 6/4 m (Light Brown); silt; coarse laminar bedding; gradational contact.
0.6 - 1.2 m	Colluvium, 7.5 YR 5/4 m (Brown); sandy silt; structureless; gradational contact.
1.2 - 9 m	Till, 7.5 YR 5/4 m (Brown); sandy silt moderately developed columnar jointing; does not stand in vertical cliffs; stone content 10%; crystallines 50%, Palaeozoic 35%, local 15%, fabric S 50° E, poor; gradational contact.
9 - 12 m	Till, 2.5 YR 4/1 m (Dark Grey); clayey silt; no structure or jointing; cohesive; stone content 5%; crystallines 35%, Palaeozoics 60%, locals 5%; fabric S 50° E, poor; gradational contact.
12 - 17 m	Till, 2.5 YR 4/1 m (Dark Grey); clayey silt; strong columnar jointing; cohesive; stone content 3%; ratios as above; fabric S 50° E, good; abrupt contact.
17 - 19 m	Fluvial silt, 2.5 YR 4/1 m (Dark Grey); laminar bedding; cohesive; non-fossiliferous; clay lenses present; bedding deformed in upper portion; gradational contact.
19 - 20 m	Silt and clay, interbedded. Silt 7.5 YR 6/2 m (Pinkish Grey); clay 7.5 YR 4/2 m (Dark Brown); both structureless, bedding irregular; cohesive.
20 - 22 m	Bearpaw Formation; dark grey shale with two interbedded bentonite layers.
BH-136	13-28-8-4-W4
0 - 1.3 m	Till, 2.5 YR 4/1 m (Dark Grey); silt; interbedded with sand, gravel and silt lenses; contorted bedding in some areas; stands in 60° cliffs; stone content 3%; fabric random; gradational lateral and vertical contacts.

Depth	Sediment Type
1.3 - 2.9 m	Lacustrine marl and silt; marl 7.5 YR 8/1 m (White), silt 7.5 YR 6/1 m (Light Grey); poorly horizontally laminated, complexly interbedded; entire sequence tilted 20° from horizontal; minor sand lenses; fossiliferous - *Pisidium sp*., *Sphaeridium sp*., Gastropods, Ostracods; stones present in trace amounts, bedding disrupted below stones; badly dumped along lower contact.
2.9 - 4.0 m	Till, 2.5 YR 4/1 m (Dark Grey); silty clay; interbedded with minor marl and silt lenses; contorted bedding; stands in 60° cliffs; stone content 3%; fabric random; to base of section.
OR-165b	13-24-7-8-W4
0 - 2.1 m	Loess, 7.5 YR 5/1 m (Grey); silt; horizontally-bedded; calcerous; stands in steep slopes; gradational lower contact.
2.1 - 2.6 m	Lacustrine silt, 7.5 YR 4/1 m (Dark Grey); horizontally bedded; stands in vertical cliffs; cohesive; stone content much less than 1%; non-fossiliferous; abrupt contact.
2.6 - 21 m	Till, 7.5 YR 4/4 m (Brown); single gravel lens, imbrication S 20° E; minor sand lenses; strong columnar jointing; cohesive; stone content 3%; crystallines 55%, Palaeozoics 30%; local 15%; fabric varies: S 70° E at base of outcrop, S 5° E at 5m depth; S 35° E at 10 m depth, S 45° E at 15 m depth; to base of section.
WH-243	S-3-1-2-W4
0 - 74 cm	Lacustrine sand, 7.5 YR 7/2 m (Pinkish Grey); medium fine grained, moderately sorted; laminar bedding; minor fine gravel beds; non-cohesive; contains diatoms; actively undergoing aeolian erosion; abrupt contact.
74 - 186 cm	Till, 7.5 YR 4/3 m (Brown); silt; structureless; non-cohesive; stone content 5%; crystallines 55%, Palaeozoics 30%, locals 15%; fabric S 60° E; to base of section.
MI-268	8-29-12-4-W4
0 - 35 cm	Brown Chernozem soil profile; Ah, Bm, Cca horizons.
35 - 102 cm	Colluvium, 7.5 YR 5/4 m (Brown); sandy silt; medium, poorly-defined laminar bedding; abrupt contact.

Depth	Sediment Type
102 - 233 cm	Loess, 7.5 YR 6/4 m (Light Brown); silt; medium; poorly-defined laminar bedding; abrupt contact.
233 - 235 cm	Volcanic ash, 7.5 YR 8/1 m (White); silt; discontinuous beds; structureless; abrupt contact.
233 - 362 cm	Loess as above; abrupt contact.
362 - 427 cm	Colluvium, as above, to base of section.

APPENDIX I: Selected Soil Profile Descriptions

MB-10 Orthic Brown Chernozem 1-24-5-6-W4

Depth	Horizon
0-12 cm	Ah. 7.5 YR 3/2 m (Brown); fine granular; very friable; abudnand fine and very fine exped roots; silt; clear wavy boundary.
12-59 cm	Btf. 7.5 YR 4/3 m (Brown); weak coarse prismatic; few fine and very fine exped roots; clayey silt; gradual wavy boundary.
59-68 cm	BC. 7.5 YR 4/2 m (Brown); massive; no roots; clayey silt to silty clay; clear wavy boundary.
68-82 cm	Cca. 7.5 YR 6/1 m (Pinkish Grey); massive, clayey silt to silty clay; gradual wavy boundary.
82 cm+	CK. Lacustrine clay. See Appendix H.

Vegetation: *Artemesia* - *Sarcobatus* - *Stipa* assemblage

Aspect: Southerly

Slope: less than 1°

Drainage: Moderate

PL-90 Dark Grey Luvisol 1-20-8-1-W4

2-0 cm	LF. Pine needles and other forest litter.
0-2 cm	AHJ. 7.5 YR 4/1 m (Dark Grey); silty loam; weak fine granular; friable; abundant fine roots; clear wavy boundary.
2-14 cm	Ae. 7.5 YR 5/1 m (Grey); silt; weak fine platy; friable; many fine roots; clear wavy boundary.
14-21 cm	AB. 7.5 YR 5/2 m (Brown); silty loam; wask angular blocky; friable; few fine roots; gradual wavy boundary.
21-26 cm	BTJ. 7.5 YR 5/2 m (Brown); silty loam; medium angular blocky, weak prismatic; friable; no roots; clear wavy boundary.
26-53 cm	Bt. 7.5 YR 5/2 m (Brown); loam; angular blocky; medium prismatic; friable; many clay skins, 2.5 Y 6/3 m (Light Yellowish Brown); gradual wavy boundary.

53-66 cm	BC. 7.5 YR 5/2 m (Brown); loam; weak prismatic; friable; few clay skins, 2.5 Y 6/3 m (Light Yellowish Brown); gradual wavy boundary.
66+ cm	C. Ravenscrag Sandstone, badly weathered.

Vegetation: *Pinus contorta* assemblage

Aspect: Northerly

Slope: On escarpment edge

Drainage: Excellent

PL-91 Dark Brown Chernozem 9-22-8-1-W4

0-15 cm	AH. 7.5 YR 3/2 m (Very Dark Brown); clay loam; very friable; strong coarse granular; abundant fine roots; clear wavy boundary.
15-18 cm	Ahe. 7.5 YR 4/2 m (Brown); clay loam; very friable; strong coarse granular; plentiful fine roots; clear wavy boundary.
18-31 cm	Bt. 7.5 YR 4/4 m (Brown); clay loam; friable; moderate coarse prismatic; few fine roots; clear wavy boundary.
31-44 cm	BC. 7.5 YR 4/4 m (Brown); clay loam; friable; weak prismatic; no roots; gradual wavy boundary.
44-67 cm	C. Cypress Hills loess. Massive; abrupt planar boundary.
67+ cm	IIC. Cypress Hills Formation.

Vegetation: *Populus* - *Betula* - *Lycopodium* assemblage

Aspect: Northerly

Slope: Less than 1 degree

Drainage: Good

PL-98 Orthic Eutric Brunisol over Orthic Humo-Ferric Podzol 14-10-8-3-W4

8-0 cm	LH. Pine needles, other forest litter.
0-2 cm	Aej. 7.5 YR 6/2 m (Pinkish Grey); sandy loam; structureless; slightly hard; many fine roots; abrupt wavy boundary.

2-12 cm	AB 7.5 YR 5/2 m (Brown); loam; crotovinas; friable; weak prismatic; few fine roots; gradual wavy boundary.
12-60 cm	Bm. 7.5 YR 6/4 m (Light Brown); loam; firm; weak prismatic, thick platy; no roots; clear wavy boundary.
60-72 cm	CK 7.5 YR 5/1 m (Brownish Grey); silt; firm; weak prismatic, clear wavy boundary. Cypress Hills loess.
72-85 cm	II Ccaj. 7.5 YR 6/2 m (Pinkish Grey); clay loam matrix in Cypress Hills conglomerate; hard; weak irregular coarse prismatic; few clay skins 2.5 Y 6/3 m (Light Yellowish Brown); gradual wavy boundary.
85-127 cm	II Bf. 2.5 YR 4/4 m (Reddish Brown); clay; hard; massive; plentiful clay skins 2.5 3/4 m (Dark Reddish Brown) on pebbles and sand grains; clear wavy boundary.
127-176 cm	II BC. 2.5 YR 4/2 m (Weak Red); clay; hard; massive; gradual wavy boundary.
176+ cm	III Ck. Cypress Hills Formation.

Vegetation: *Pinus contorta* assemblage

Aspect: Northwesterly

Slope: On escarpment edge

Drainage: Excellent

PL-100	Orthic Dystic Brunisol	8-15-8-3-W4
6-0 cm	LF. Pine needles, other forest litter.	
0-6 cm	Aej. 5 YR 6/1 m (Light Grey); silt; very friable; granular; few large exped, many fine exped roots; clear wavy boundary.	
6-32 cm	Bfj. 5 YR 6/6 m (Reddish Yellow); sandy silt; friable, weak granular; few medium exped roots; clear wavy boundary.	
32-74 cm	C. Colluvial deposit. Sand silt; massive; few fine roots; gradual wavy boundary.	
74+ cm	Ck. Cypress Hills Formation.	

Vegetation: *Pinus* - *Populus* assemblage

Aspect: Northeast

Slope: 10 degrees; at base of escarpment

Drainage: Moderate to fair

FX-107 Eluviated Black Chernozem 14-18-7-2-W4

0-7 cm	Ah. 10 YR 2/1 m (Black); silty clay; very friable; weak granular; many fine and very fine roots; clear wavy boundary.
7-11 cm	Ahe. 7.5 YR 4/1 m (Dark Grey); silt; very friable; fine weak platy; plentiful very fine roots; clear wavy boundary.
11-35 cm	BC. 7.5 YR 4/2 m (Brown); clayey silt; slightly firm, plentiful clay skins, 7.5 YR 7/2 m (Pinkish Grey); clear broken boundary.
35-38 cm	Cca. Discontinuous. 7.5 YR 6/2 m (Pinkish Grey); clayey silt; slightly firm; clear wavy boundary.
38+ cm	C. Cypress Hills loess.

Vegetation: *Artemisia* - *Stepa* - *Festuca* assemblage

Aspect: Southeast

Slope: On escarpment edge

Drainage: Excellent

APPENDIX J: Soil Chemistry

LOCATION	HORIZON	ORGANIC CARBON*	C/N**	Fe+Al[1]	pH	CLAY
El-2 0-10	Ah	1.06%	14.7	-	7.6	20%
El-2 63-69	Ahb	1.23	10.4	-	7.9	18
El-2 275-83	Ahb	1.07	13.6	-	7.9	22
El-2 644-61	Ahb	1.19	16.8	-	7.9	21
El-3 209-23	Bfgb	0.41	-	0.73	6.9	12
El-4 89-98	Ahb	1.42	11.6	-	8.1	22
El-4 180-212	Btb	0.54	6.9	0.27	7.6	47
El-4 390-393	Bfgb	0.37	-	0.76	6.5	17
El-5 129-135	Aheb	0.66	9.3	-	7.4	15
El-5 382-437	Bfgb	0.26	-	0.88	6.4	10
El-6 570-575	Ahb	1.63	9.7	-	7.9	23
El-7 306-314	Aheb	0.37	8.9	-	7.6	15
El-8 257-62	Ahb	0.62	8.6	-	7.8	17
MB-10 0-12	Ah	1.95	11.3	-	7.9	21
MB-10 12-59	Btj	0.73	5.8	-	7.8	29
PL-91 0-15	Ah	2.21	8.7	-	8.0	19
PL-91 18-31	Bt	0.76	5.7	-	7.6	39
PL-98 12-60	Bm	0.37	6.0	0.29	7.8	25
PL-98 85-127	II Bf	0.13	-	0.63	7.3	28
PL-100 6-32	Bfj	0.44	-	0.60	6.9	17

*Walkley-Black method (McKeague, 1978)

**Nitrogen by semi-Micro Kjeldhal method (McKeague, 1978)

[1] Pyrophosphate-extractable (McKeague, 1978)

APPENDIX K: Till Fabric Analyses

SAMPLE	PHASE	ORIENTATION
MB-7	B	S45 E
R-24	B	S40 E
R-24	B?	S35 E
IR-26	C	S5 E
IR-28	C	S0 E
IR-28	C	S0 E
IR-29	C	S0 E
R-33	B	S35 E
IR-376	C	S5 W
W-47b	C	S0 E
W-47b	C	S5 E
W-52	B	S30 E
W-53	B	S30 E
W-53	B	S35 E
W-53	pre-A	S60 E
W-53	A	S40 E
W-54	B	S40 E
IR-57	C	S0 E
WH-62	B	S60 E
WH-63	B	S50 E
WH-70	B	S45 E
WH-73	B	S40 E
OF-74	B	S40 E
OF-75	B	S40 E
MR-78	B	S37 E
CC-80	B	S35 E
BH-120	C	S10 E
BH-121	C	S5 E
BH-122a	B	S50 E
BH-122a	B	S50 E
LP-125	B	S40 E
LP-129	B	S35 E
T-132	B	S45 E
T-133	B	S50 E
BH-134	B	S30 E
T-148	B	S40 E
T-149c	B	S45 E
T-150a	B	S50 E
T-151c	B	S45 E
T-152	B	S40 E
T-154	B	S40 E
T-155	B	S45 E
T-156b	B	S45 E
T-157	B	S35 E
T-158	B	S40 E
SP-161	C	S0 E
SP-162	C	S5 E
SP-164c	C	S10 E

SAMPLE	PHASE	ORIENTATION
OR-165b	B-C	S5-70 E*
OR-168	C	S10 E
MB-175	B	S35 E
MB-222	B	S45 E
GV-237	B	S45 E
GV-238	B	S45 E
JD-239	B	S50 E
WH-243	B	S60 E
E-245	B	S50 E
JD-279	B	S55 E

*See Appendix H

APPENDIX L: Phytoplankton Analysis

SAMPLE	PHYTOPLANKTON*		ENVIRONMENT
Core 1 236-269 cm	*Navicula sp*	61%	Mesotrophic Stream
	Melosira granulata	21%	
	Dinobryon sp	16%	
	Xanthidium sp	2%	
Core 1 599-680 cm	*Melosira italica*	39%	Oligotrophic Stream
	Navicula sp	38%	
	Xanthidium sp	12%	
	Closterium paravulum	8%	
	Dinobryon sp	3%	
Core 2 368-442 cm combined horizons	*Navicula sp*	49%	Oligotrophic Stream
	Melosira italica	39%	
	Xanthidium sp	10%	
	Dinobryon sp	2%	
Core 2 512-554 cm	*Microcystis sp*	69%	Shallow pond
	Anabaena sp	28%	
	Surirella sp	2%	
Core 2 544-638 combined horizons	*Melosira italica*	51%	Oligotrophic Stream
	Navicula sp	38%	
	Melosira granulata	10%	
	Xanthidium sp	1%	
Core 3 193-198 cm	*Microcystis sp*	89%	Shallow pond
	Anabaena sp	10%	
Core 4 393-401 cm	*Microcystis sp*	86%	Shallow pond
	Anabaena sp	12%	
Core 5 327-342 cm	*Microcystis sp*	83%	Shallow pond
	Anabaena sp	12%	
	Surirella sp	2%	
	Aphanizomenon sp	2%	
Core 5 437-446 cm	*Microcystis sp*	77%	Shallow pond
	Anabaena sp	21%	
	Aphanizomenon sp	2%	
Core 6 380-390 cm	*Microcystis sp*	66%	Shallow pond
	Anabaena sp	30%	
	Aphanizomenon sp	3%	

SAMPLE	PHYTOPLANKTON		ENVIRONMENT
Core 7 434-452 combined horizons	*Microcystis sp*	78%	Shallow pond
	Anabaena sp	19%	
	Diatoma sp	2%	
	Aphanizomenon sp	1%	
Core 7 739-745	*Microcystis sp*	89%	Shallow pond
	Anabaena sp	10%	
	Aphanizomenon sp	1%	
Core 8 392-398	*Microcystis sp*	82%	Shallow pond
	Anabaena sp	11%	
	Aphanizomenon sp	6%	
Wild Horse I composite	*Tabellaria sp*	29%	Oligotrophic
	Asterionella sp	27%	
	Navicula sp	20%	
	Melosira italica	18%	
	Fragilaria crotonensis	5%	
Wild Horse II composite	*Stephanodiscus sp*	34%	Mesotrophic
	Cerateum sp	27%	
	Melosira granulata	20%	
	Fragilaria crotonensis	19%	
Wild Horse III composite	*Melosira distans*	46%	Eutrophic
	Eutonia sp	40%	
	Fragilaria crotonensis	8%	
	Microcystis sp	2%	
CanalCreek I composite	*Asterionella sp*	56%	Oligotrophic
	Melosira italica	27%	
	Tabellaria sp	13%	
	Navicula sp	3%	
Canal Creek II composite	*Melosira italica*	82%	Oligotrophic
	Asterionella sp	10%	
	Xanthidium sp	6%	
	Dinobryon sp	2%	
Gahern composite	*Melosira granulata*	35%	Mesotrophic
	Fragilaria crotonensis	32%	
	Navicula sp	17%	
	Stephanodiscus sp	10%	
	Cerateum sp	4%	
	Diatoma sp	1%	

SAMPLE	PHYTOPLANKTON		ENVIRONMENT
Manyberries I composite	*Melosira italica*	38%	Oligotrophic
	Tabellaria sp	32%	
	Navicula sp	23%	
	Asterionella sp	6%	
Manyberries II composite	*Melosira italica*	93%	Oligotrophic
	Navicula sp	3%	
	Asterionella sp	3%	
Orion II composite	*Fragilaria crotonensis*	39%	Mesotrophic
	Stephanodiscus sp	31%	
	Melosira granulata	16%	
	Cerateum sp	10%	
	Navicula sp	3%	
Calib composite	*Microcystis sp*	75%	Eutrophic salinity 1000-5000 ppm
	Anabaena sp	19%	
	Chaetoceros sp	3%	
	Surirella sp	2%	
	Aphanizomenon sp	1%	
Modern Lake Pakowki PK-252	*Microcystis sp*	36%	Eutrophic
	Anabaena sp	24%	
	Aphanizomenon sp	19%	
	Surirella sp	6%	
	Melosira granulata	2%	
	Asterionella sp	1%	
	Fragilaria crotonensis	1%	

APPENDIX M: Mollusc fragments, Site DjOn-26 Cores

SAMPLE	FRAGMENTS RECOVERED	
Core 1 412-431 cm	*Pisidium casertaneum*	5
	Pisidium sp	3
	Stagnicola palustus	2
	Succinea sp	1
Core 1 440-476 cm	*Pisidium sp*	3
	Vertigo modesta	2
	Stagnicola palustus	2
	Physa sp	2
Core 1 714-855	*Pisidium nitidium*	1
	Pisidium sp	3
	Vertigo modesta	3
	Succinea sp	1
	Stagnicola palustus	1
	Physa sp	1
	indeterminate	6
Core 3 158-168 cm	*Vallonia gracilicosta*	3
	Vertigo modesta	3
Core 3 242-272 cm	*Pisidium casertaneum*	6
	Pisidium nitidium	1
	Pisidium sp	1
	Vertigo modesta	5
	Vallonia gracilicosta	1
	Physa sp	1
Core 4 596-660 cm	*Pisidium sp*	2
	Vertigo modesta	4
	Stagnicola palustus	1
	Succinea sp	1
	indeterminate	11
Core 5 135-167 cm	*Vertigo modesta*	7
	Succinea sp	1
Core 5 228-257	*Vertigo modesta*	5
	Physa sp	1
	Succinea sp	1
Core 5 382-437 cm	*Pisidium casertaneum*	2
	Pisidium sp	4
	Vallonia gracilicosta	3
	Vertigo modesta	2
	Stagnicola palustus	1
	Physa sp	2

SAMPLE	FRAGMENTS RECOVERED	
Core 6 182-272 cm	*Pisidium nitidium*	4
	P. casertaneum	3
	Vertigo modesta	3
	Succinea sp	1
	indeterminate	3
Core 6 903-912 cm	*Pisidium sp*	3
Core 8 307-392 cm	*Vertigo modesta*	5
	Vallonia gracilicosta	2
	Stagnicola palustus	1
	indeterminate	3

APPENDIX N - Mollusc Fragments, Lacustrine Sediments

Locality	Species	Percentage of Identifiable Fragments
Wild Horse II composite	*Vertigo modesta*	67%
	Succinea avara	33%
Wild Horse III composite	*Vertigo modesta*	50%
	Discus cronkhitei	24%
	Oreohelix sp.	14%
	Zonitoides sp.	7%
	Retinella sp.	5%
Canal Creek I composite	*Pisidium nitidum*	38%
	P. casertaneum	12%
	Ferrisia kirklandi	6%
	Vertigo modesta	24%
	Succinea sp.	12%
	Physa sp.	6%
Canal Creek II composite	*Pisidium nitidum*	33%
	P. casertaneum	11%
	Ferrissia kirklandi	11%
	Vertigo modesta	22%
	Vallonia sp.	11%
	Physa sp.	11%
Gahern composite	*Lymnaea stagnalis*	25%
	Helisoma sp.	25%
	Valvata tricarinata	25%
	Pisidium sp.	25%
Orion I composite	*Vertigo modesta*	100%
Orion II composite	*Vertigo modesta*	100%
Calib composite	*Pisidium variable*	29%
	P. casertaneum	14%
	Vertigo modesta	29%
	Physa sp.	7%
	Succinea sp.	21%

W-53	*Pisidium nitidum*	25%
	P. variable	13%
	Pisidium sp.	63%
CC-80	*Pisidium sp.*	100%
BH-136	*Pisidium sp.*	30%
	Sphaeridium sp.	30%
	Vertigo modesta	30%
	Physa sp.	10%

APPENDIX O: Phytolith Counts, Site DjOn-26 (E-1)

HORIZON	ELONGATE	PANICOID	INDETERMINATE
Core 1 0-73 cm	56%	31%	13%
Core 2 0-28 cm	59%	30%	11%
Core 2 94-99 cm	48%	37%	15%
Core 2 315-326 cm	44%	42%	14%
Core 3 60-75 cm	39%	40%	21%
Core 4 0-30 cm	19%	39%	42%
Core 5 0-27 cm	27%	38%	35%
Core 6 50-55 cm	38%	49%	13%
Core 6 63-77 cm	33%	56%	11%
Core 8 0-84 cm	50%	44%	6%
Core 8 180-191 cm	37%	52%	11%

APPENDIX P: Pebble Composition of Gravel Beds, Site DjOn-26.

	Ravenscrag Sandstone	Frenchman Sandstone	Argillite	Quartzite	Trachyte	Ironstone	Acidic Crystallines	Basic Crystallines	Paleozoic Carbonates	Athabasca Sandstone
Core 1 406-412 cm	26	2	15	46	-	-	1	-	-	-
Core 1 431-440 cm	15	-	9	37	-	-	-	-	-	-
Core 1 476-543 cm	84	3	27	136	1	3	3	1	-	-
Core 1 714-855 cm	69	-	15	99	2	4	15	6	4	1
Core 2 120-132 cm	15	-	3	3	-	-	-	-	-	-
Core 2 442-512 cm	93	6	33	154	-	5	4	2	1	-
Core 2 675-686 cm	11	-	2	16	-	-	3	1	1	-
Core 4 660-668 cm	15	-	-	17	-	-	-	-	-	-
Core 5 342-376 cm	42	-	-	29	-	-	1	-	-	-
Core 5 484-600 cm	69	-	6	44	2	6	3	1	-	-
Core 6 869-912 cm	16	-	3	24	-	-	8	3	2	-
Core 6 916-944 cm	5	2	-	17	-	-	17	3	-	1
Core 7 1050-1080 cm	12	-	2	26	-	-	7	2	-	-

APPENDIX Q: Ostracod Fragments, Lacustrine Sediments

		Fragments Recovered
Wild Horse I composite	*Limnocythere staplini*	8
	Candona obtusa	5
	C. rostrata	2
	Cypris pubera	2
Wild Horse II composite	*Potomocypris smaragdina*	8
	Cypridopsis vidua	2
W-53	*Limnocythere staplini*	4
	Cypridopsis vidua	2
CC-80	*Candona obtusa*	6
BH-136	*Candona obtusa*	5
	C. rostrata	3
	Cypris pubera	1

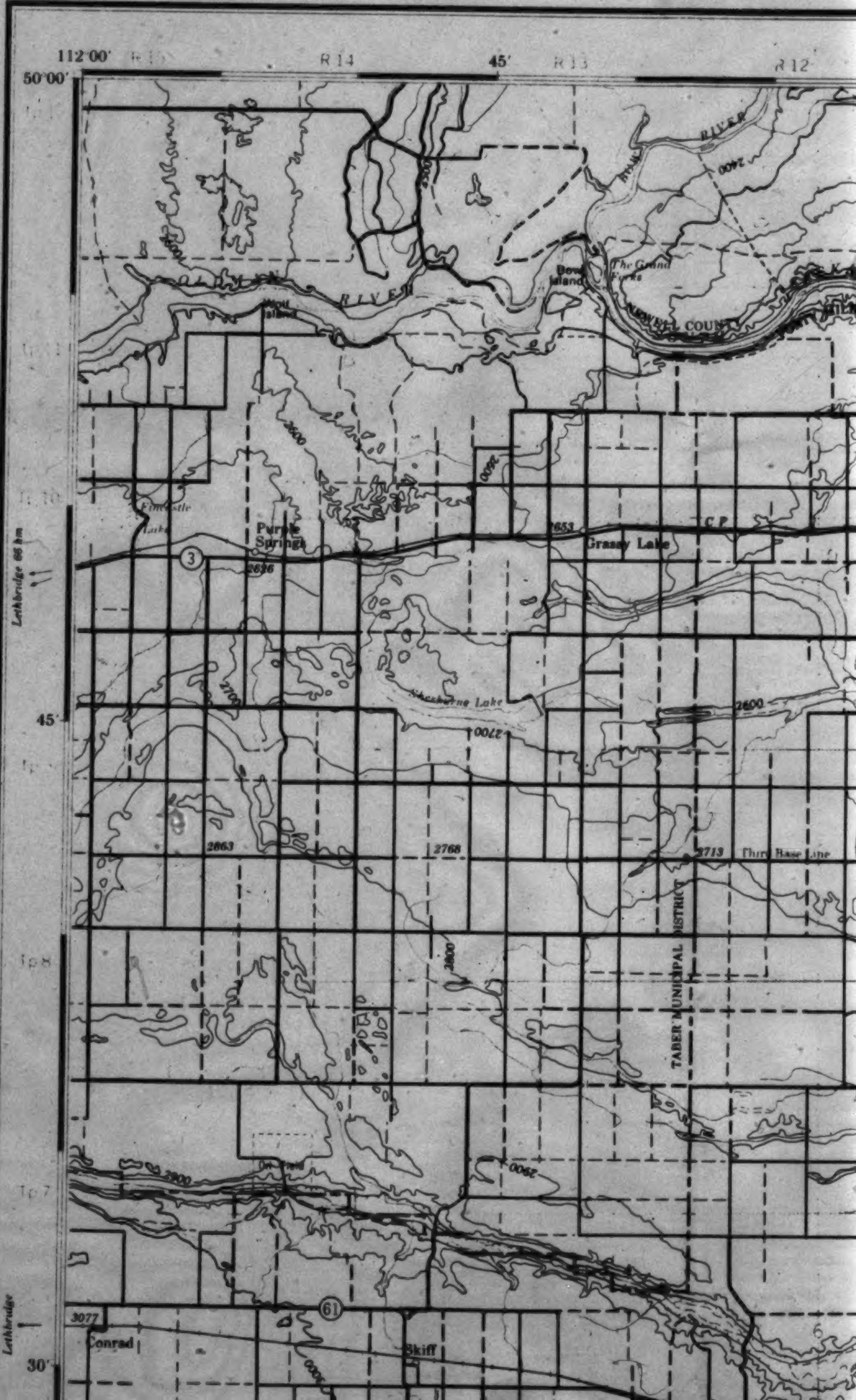
1 OF

FIGURE 2. Wester

The Figure illust
Cypress Hills reg
are the locations

72 E

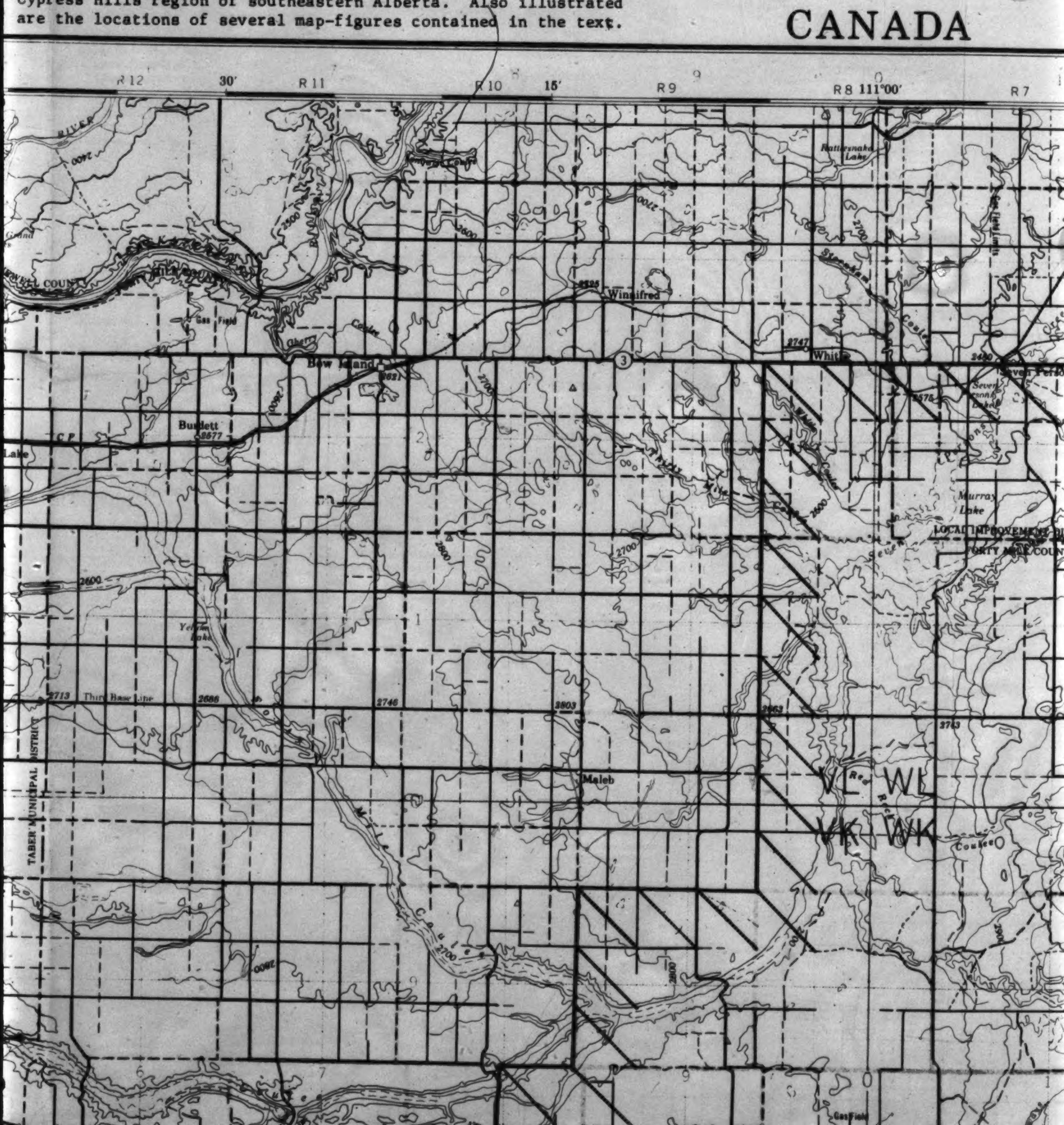
1:250,000


112°00'
R 15
R 14
45'
R 13
R 12
50°00'
2400
RIVER
RIVER
Bow Island
The Grand Forks
NEWELL COUNTY
2600
Finnastle Lake
Purple Springs
3
2636
2653
Grassy Lake
C P
Lethbridge 66 km
Sherburne Lake
2700
2600
45'
2663
2768
2713
Third Base Line
TABER MUNICIPAL DISTRICT
Tp 8
2600
2900
Tp 7
2900
61
3077
Conrad
Skiff
Lethbridge
30'

20F

FIGURE 2. Western Cypress Hills Region

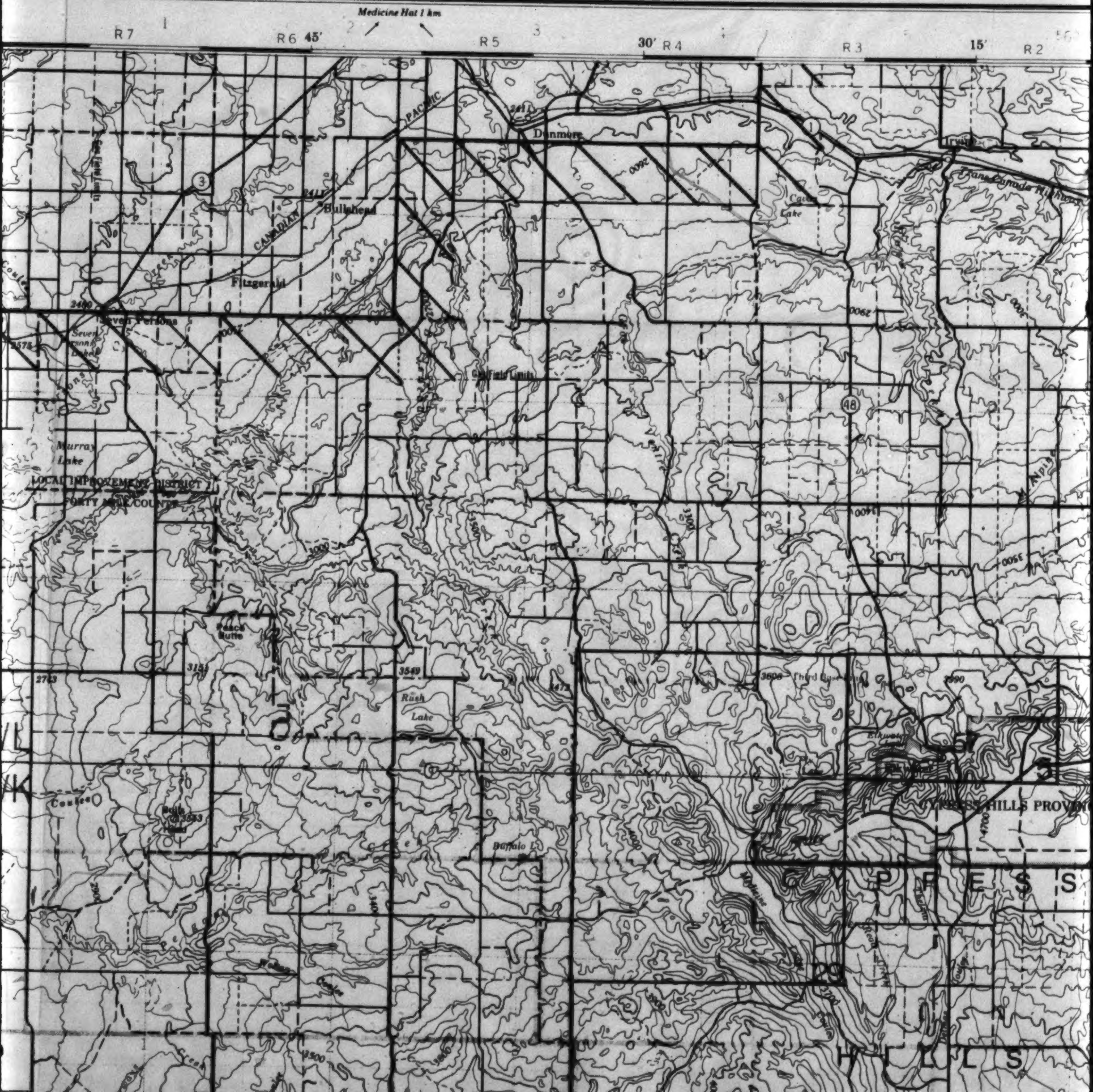
The Figure illustrates the extent of the study area in the western Cypress Hills region of southeastern Alberta. Also illustrated are the locations of several map-figures contained in the text.


CANADA
R 12
30′
R 11
R 10
15′
R 9
R 8
111°00′
R 7
RIVER
2400
Grand
2500
2600
2700
Rattlesnake Lake
Winnifred
2595
Gas Field
Coulee
Bow Island
2621
3
2747
Whitla
2480
Seven Persons
Seven Persons Lake
2575
Burdett
2577
C.P.
Lake
Murray Lake
LOCAL IMPROVEMENT DI
FORTY MILE COUNTY
Yellow Lake
2713
Third Base Line
2686
2746
2803
2663
2743
TABER MUNICIPAL DISTRICT
Maleb
VL
WL
VK
WK
Coulee
2800
Gas Field

3 OF

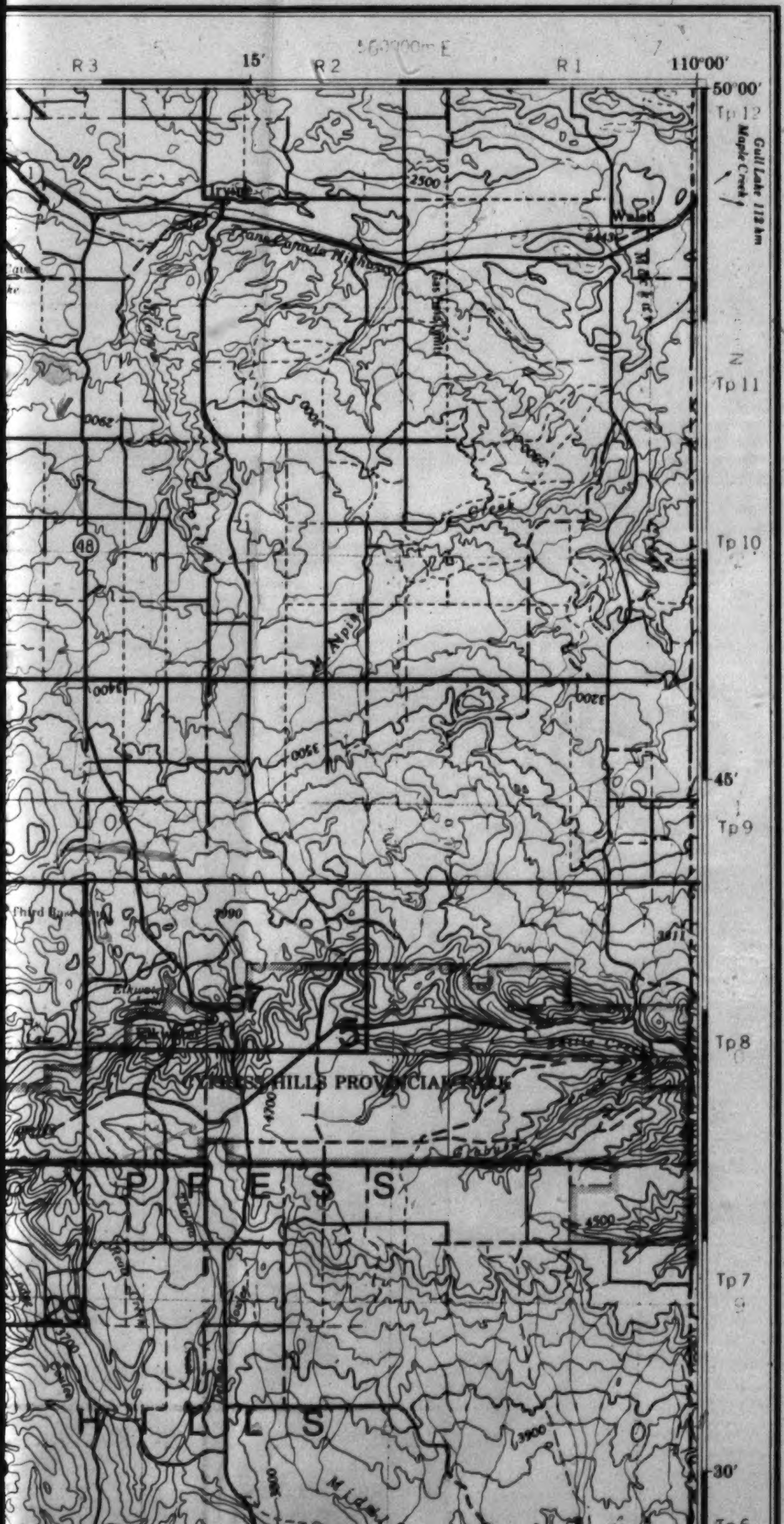
ADA

EDITION 3



Medicine Hat 1 km
R 7
R 6
45'
R 5
30'
R 4
R 3
15'
R 2
1
2
3
CANADIAN PACIFIC
Dunmore
Bullshead
Fitzgerald
Seven Persons
Seven Persons Coulee
Cavan Lake
Irvine
Trans-Canada Highway
3
1
48
Gas Field Limits
Murray Lake
LOCAL IMPROVEMENT DISTRICT 1
FORTY MILE COUNTY
Peace Butte
Rush Lake
Buffalo L.
Third Butte
Elkwater
CYPRESS HILLS PROVINCIAL
CYPRESS
HILLS
Coulee
Creek
2400
2578
2900
3000
3131
3500
3540
3606

EDITION 3 **72 E**

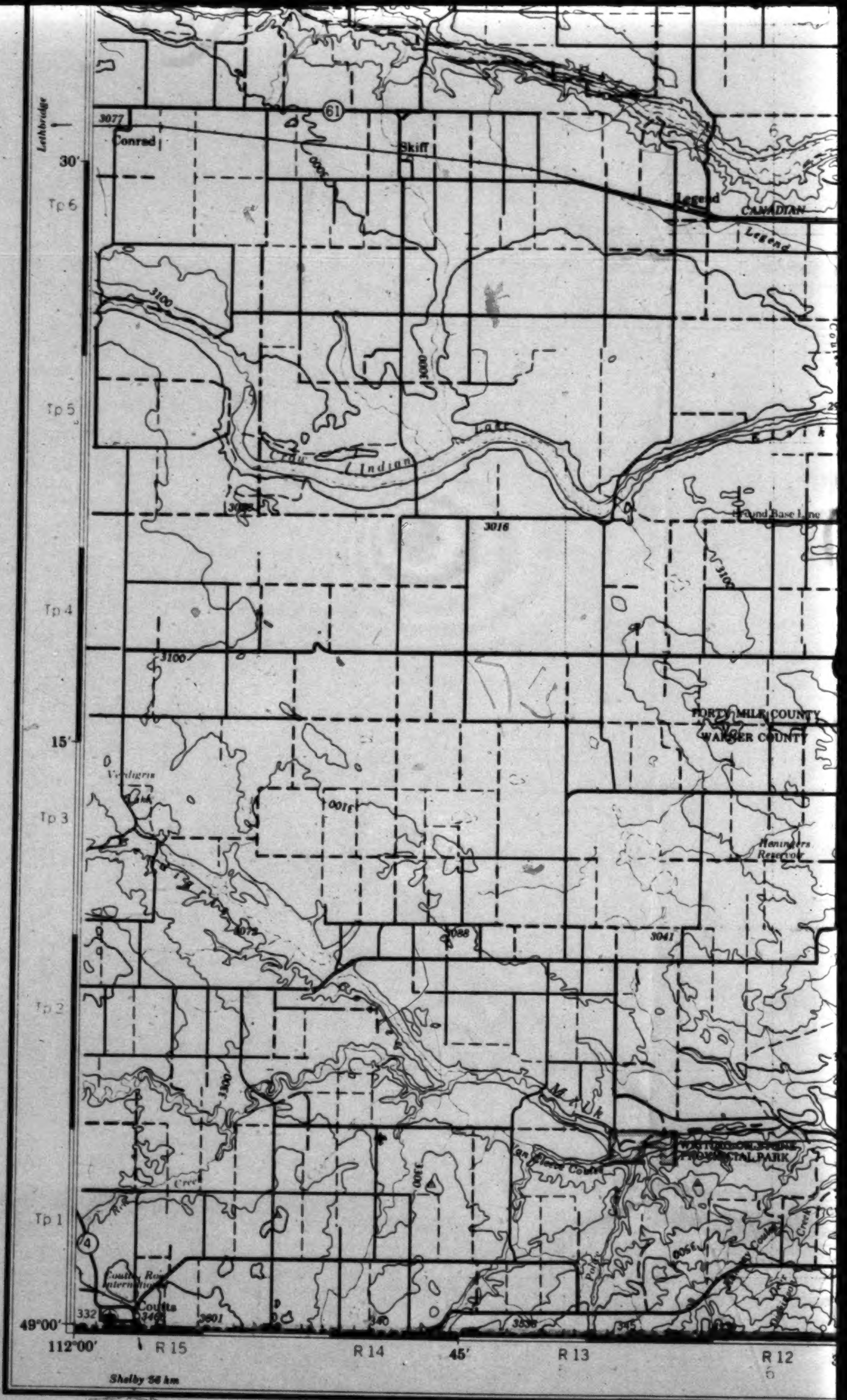

560000m E
R 3
15′
R 2
R 1
110°00′
50°00′
Tp 12
Gull Lake 112 km
Maple Creek
Walsh
Trans Canada Highway
2500
Tp 11
48
Tp 10
3500
45′
Tp 9
Tp 8
CYPRESS HILLS PROVINCIAL PARK
C Y P R E S S
4500
Tp 7
H I L L S
3900
30′

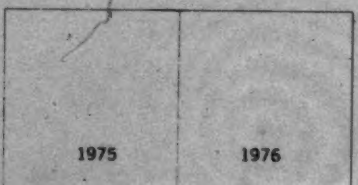
Military users, refer to this map as. Référence de cette carte pour usage militaire.	SERIES	A 502	SÉRIE
	MAP	72 E	CARTE
	EDITION	3 MCE	ÉDITION

40F

TEN THOUSAND METRE
UNIVERSAL TRANSVERSE MERCATOR GRID
ZONE 12
QUADRILLAGE DE DIX MILLE MÈTRES
TRANSVERSE UNIVERSEL DE MERCATOR

50F


Lethbridge
Conrad
3077
61
Skiff
3000
Legend
CANADIAN
Legend
30'
Tp 6
3100
Tp 5
Crow Indian Lake
3088
3016
Second Base Line
3100
Tp 4
3100
FORTY MILE COUNTY
WARNER COUNTY
15'
Verdigris Lake
3100
Tp 3
Heninger Reservoir
3075
3088
3041
Tp 2
Milk
3300
WRITING-ON-STONE PROVINCIAL PARK
Police Coulee
Creek
Tp 1
4
Coutts
3401
Creek
3300
Coulee
332
3465
3801
3400
3530
345
49°00'
112°00'
R 15
R 14
45'
R 13
R 12
6
Shelby 56 km



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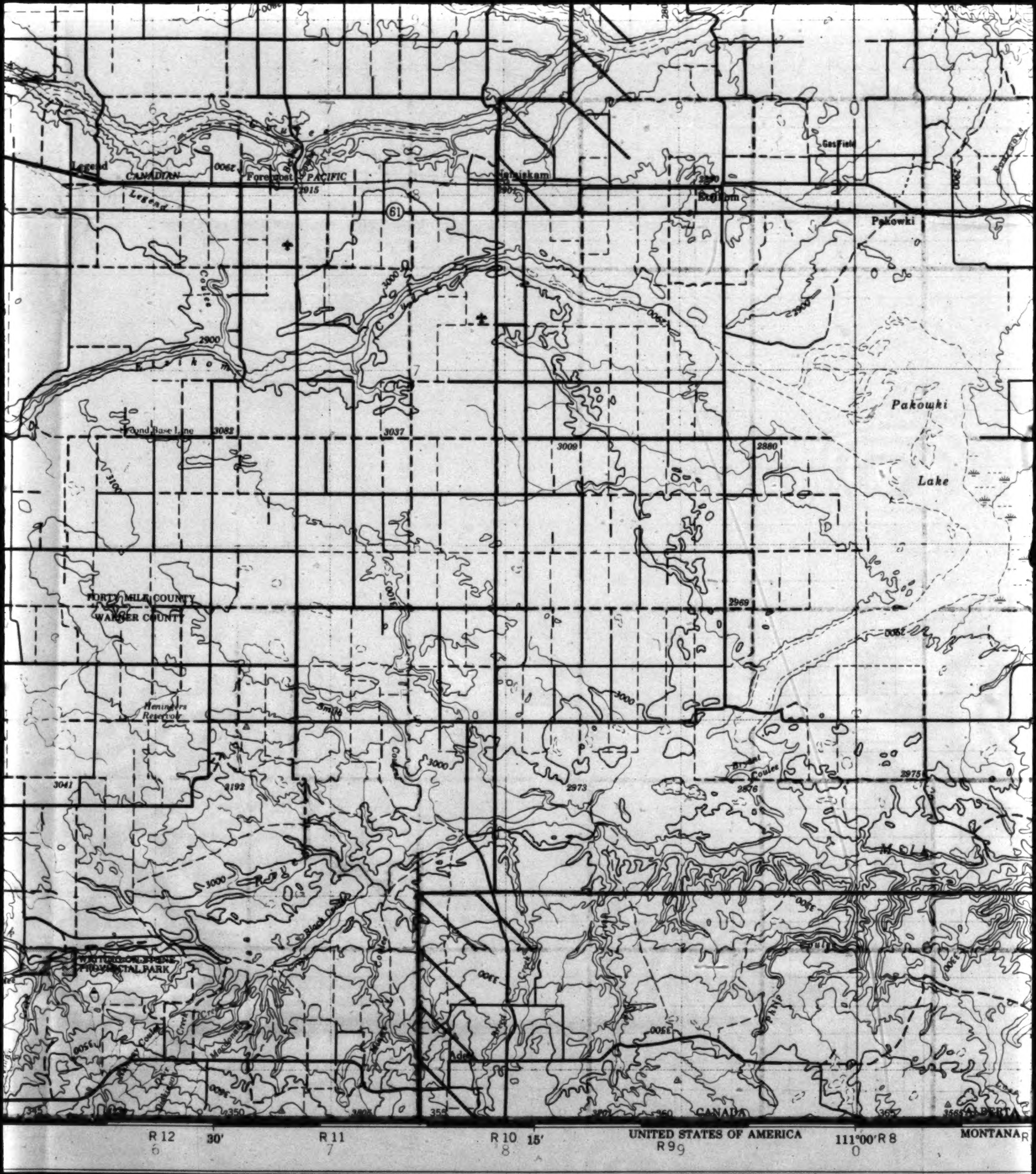
Department of Energy, Mines and


Legend
CANADIAN
Foremost
PACIFIC
Nemiskam
Etzikom
Pakowki
Gas Field
61
Legend
Coulee
Etzikom
Second Base Line
Pakowki
Lake
FORTY MILE COUNTY
WARNER COUNTY
Heninger's Reservoir
Smith
Coulee
Bryant Coulee
Milk
Red
Black Coulee
WRITING-ON-STONE PROVINCIAL PARK
Macdonald Creek
Verdigris
Aden
CANADA
ALBERTA
UNITED STATES OF AMERICA
MONTANA
R 12
30'
R 11
R 10
15'
R 9
111°00' R 8
6
7
8
9
0

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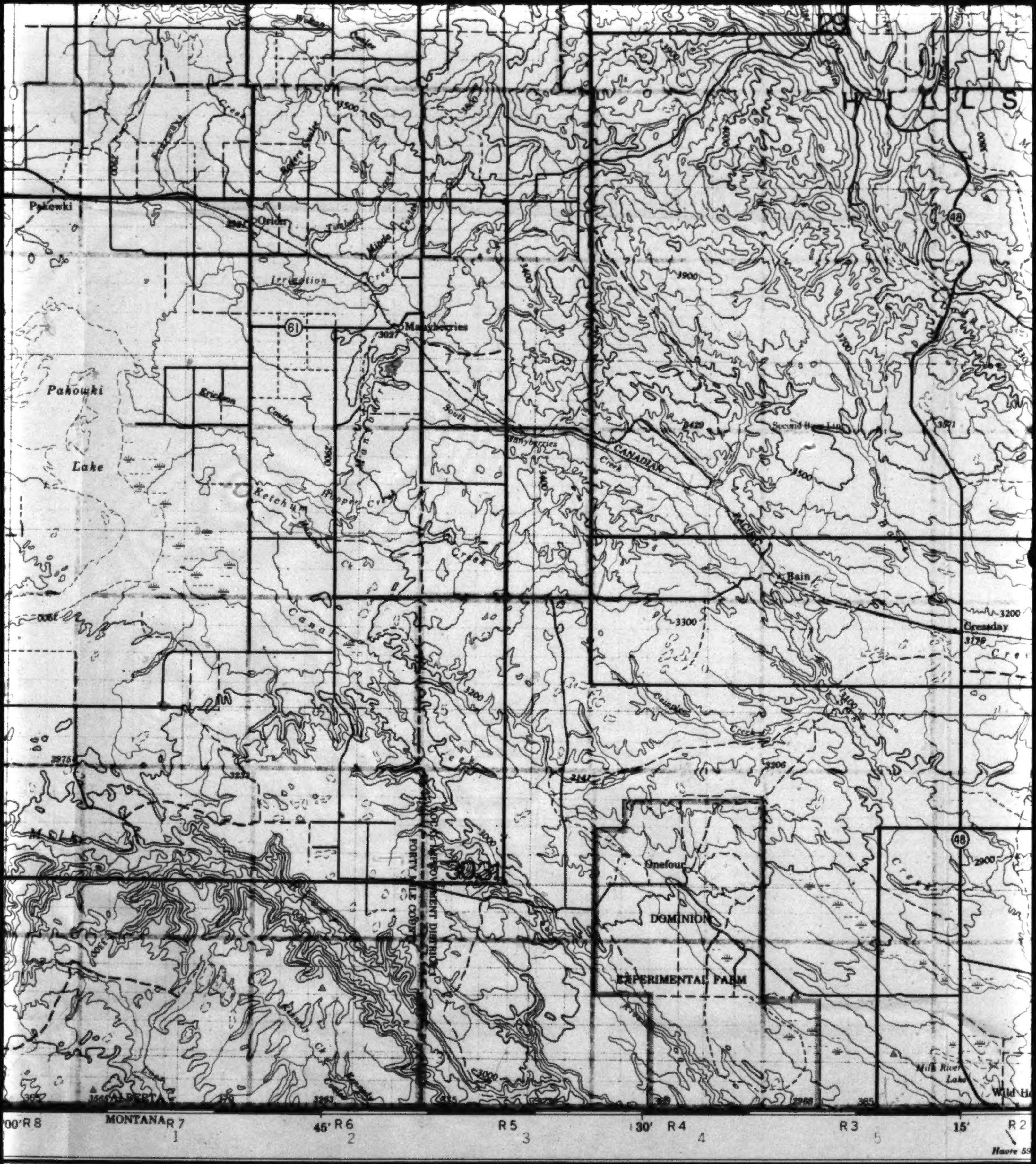
60F

FOREMOST
ALBERTA-SASKATCHEWAN


Pakowki
Orion
Manyberries
Pakowki
Lake
Erickson Coulee
Irrigation
Ketchum Creek
Canal
Hooper Creek
South
Manyberries Creek
CANADIAN PACIFIC
Bain
Cressday
Second Hay Lake
Onefour
DOMINION
EXPERIMENTAL FARM
Milk River Lake
Wild Horse
H I L L S
FORTY MILE COULEE IMPROVEMENT DISTRICT
ALBERTA
MONTANA
61
48
3900
3700
3500
3400
3300
3200
3100
3000
2900
3037
3429
3371
3179
3206
3142
2975
3232
2988
385
30 31
29
R 8
R 7
R 6
R 5
R 4
R 3
R 2
45'
30'
15'
1
2
3
4
5
Havre 59

MOST
KATCHEWAN

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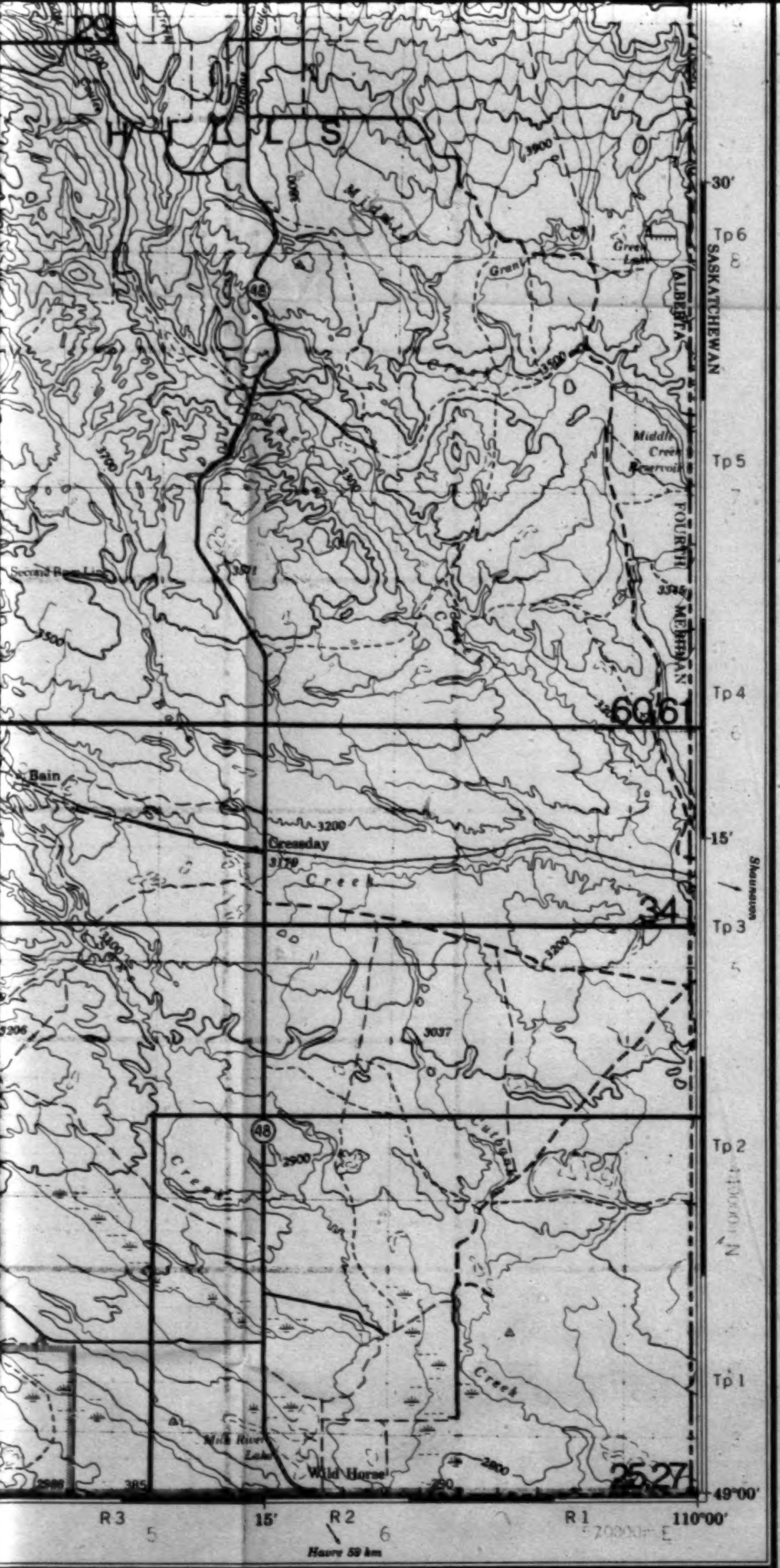
70F


H I L L S
Middle Creek
Green Lake
Middle Creek Reservoir
SASKATCHEWAN
ALBERTA
FOURTH MERIDIAN
Second Base Line
Bain
Cressday
Creek
Shaunavon
Lodge Creek
Milk River Lake
Wild Horse
Havre 59 km
48
3900
3500
3700
3300
3571
3335
3200
3170
3037
2900
2800
29
60 61
34
25 27
30'
15'
49°00'
Tp 6
Tp 5
Tp 4
Tp 3
Tp 2
Tp 1
R 3
R 2
R 1
15'
110°00'
5
6
7
8
5
6
5500000m N
700000m E

TEN THOUSAND METRE

UNIVERSAL TRANSVERSE MERCATOR GRID

ZONE 12

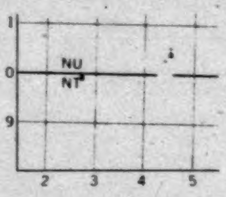
QUADRILLAGE DE DIX MILLE MÈTRES

TRANSVERSE UNIVERSEL DE MERCATOR

GRID ZONE DESIGNATION DESIGNATION DE LA ZONE DU QUADRILLAGE	100.000 m SQUARE IDENTIFICATION IDENTIFICATION DU CARRE de 100.000 m
12 U	VL WL VK WK 55 5

EXAMPLE OF METHOD USED
TO GIVE A REFERENCE TO NEAREST 1000 METERS

EXEMPLE DE LA MÉTHODE EMPLOYEE
POUR FIXER DES REPÈRES A 1000 MÈTRES PRÈS


1
0
9
NU
NT
2
3
4
5

REFERENCE POINT POINT DE REPÈRE	CHURCH-ÉGLISE	(as above) (ci-dessus)

SQUARE Read letters of 100.000m square
CARRE Lire les lettres du carre de 100.000m — NU

EASTING Read number on grid line immediately to left of point
LONGITUDE EST Noter le chiffre de la ligne du quadrillage immediatement a gauche du repere — 4
Estimate tenths of a square from this line eastward to point
Estimer le nombre de dixiemes du carre entre cette ligne et le repere en direction est — 5
45

NORTHING Read number on grid line immediately below point
LATITUDE NORD Noter le chiffre de la ligne du quadrillage immediatement en dessous du repere — 0
Estimate tenths of a square from this line northward to point
Estimer le nombre de dixiemes du carre entre cette ligne et le repere en direction nord — 4
04

GRID REFERENCE
REFERENCE AU QUADRILLAGE — NU4504

If reporting beyond 18 in any direction, prefix Grid Zone designation as 14VNU4504

Si vous faites connaitre votre position a quelqu'un qui se trouve à plus de 18 peu importe la direction indiquez egalement la zone du quadrillage tel que 14VNU4504

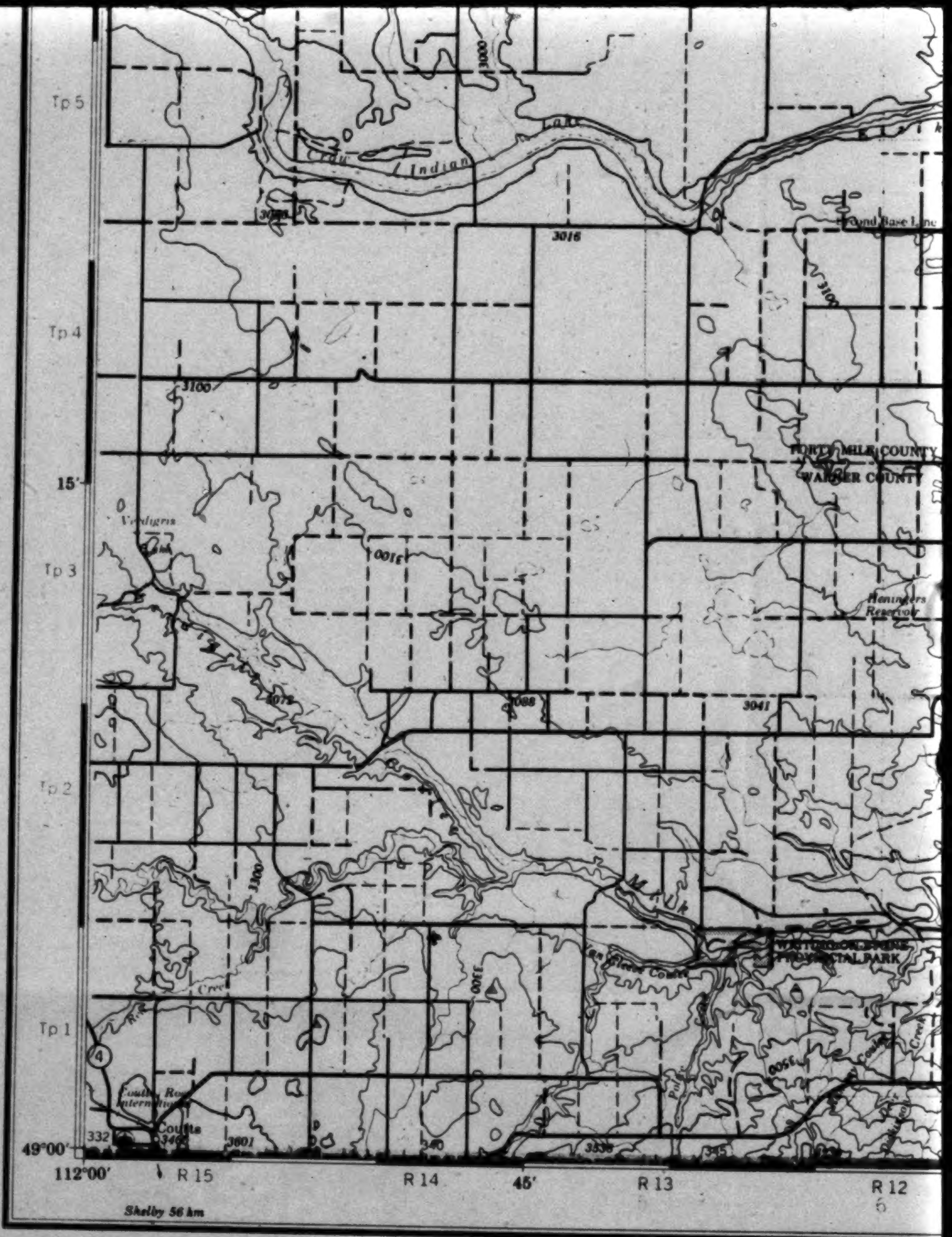
80F

TOGRAPHIE,
S.SOURCES.
ls qu'indiqués

eda,
ttawa,

rce

114° 51°		108° 51°
82 I	72 L	72 K
82 H	72 E	72 F


Tp 5
Crow Indian Lake
Second Base Line
3016
Tp 4
3100
FORTY MILE COUNTY
WARNER COUNTY
15'
Verdigris Lake
Tp 3
Heningers Reservoir
3041
3088
Tp 2
Milk River
WRITING-ON-STONE PROVINCIAL PARK
Tp 1
4
Coutts
332
3601
340
345
49°00'
112°00'
R 15
R 14
45'
R 13
R 12
6
Shelby 56 km

1975	1976

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Department of Energy, Mines a

Roads:

hard surface, all weather.......................... du

hard surface, all weather..........................

loose or stabilized surface, all weather........ 2 la

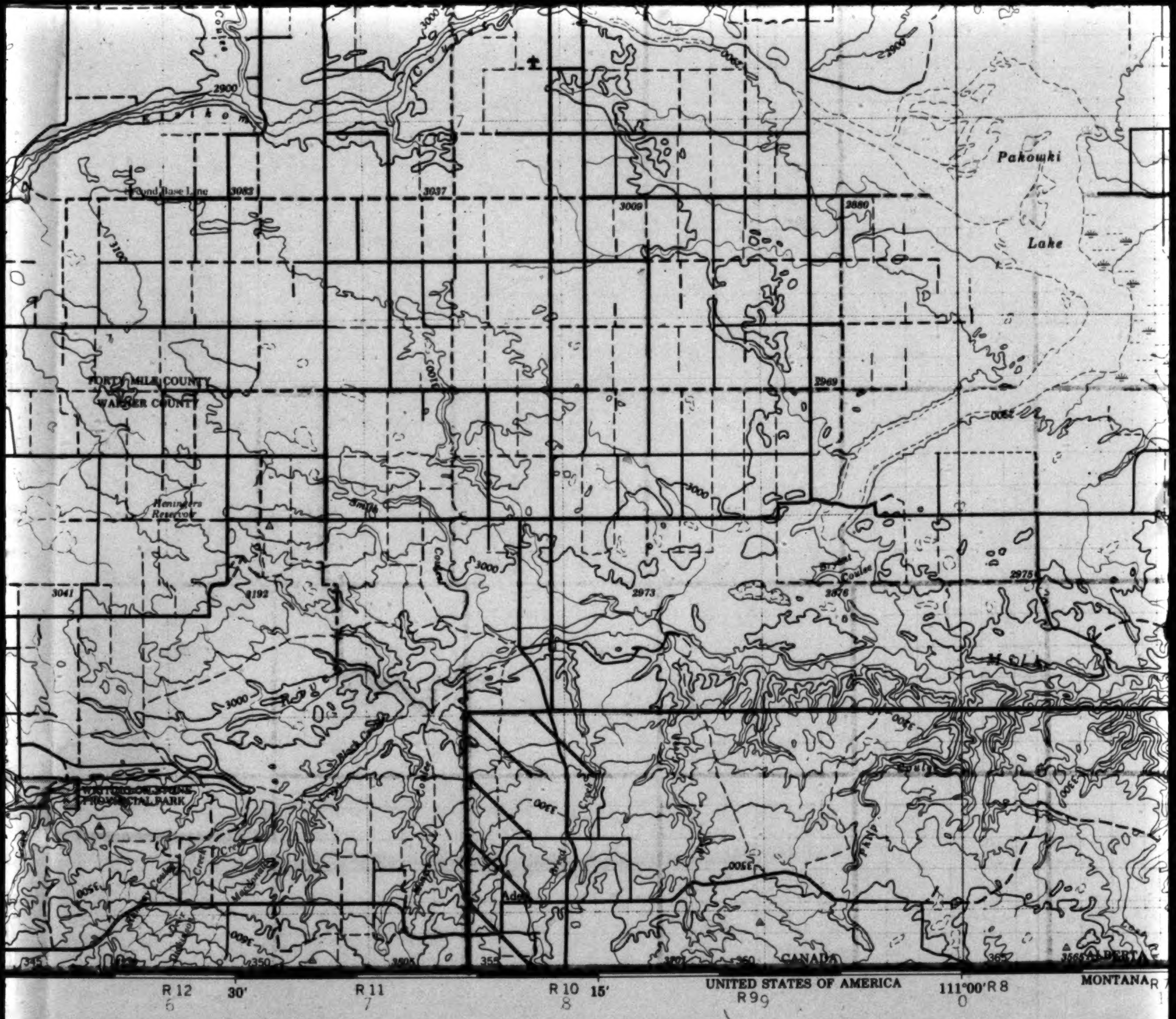
loose surface, dry weather..........................

cart track..

trail, cut line or portage...........................

FOR COMPLETE REFERENCE S

90F


Coulee
2900
Etzikom
Second Base Line
3082
3037
3009
3880
2900
Pakowki
Lake
3100
FORTY MILE COUNTY
WARNER COUNTY
Heningers Reservoir
Smith
3000
2969
3041
3192
2973
3876
2975
Coulee
3000
Milk
WRITING-ON-STONE PROVINCIAL PARK
Black
3300
3500
Macdonald
Creek
Aden
3600
345
350
3505
355
360
CANADA
365
ALBERTA
R 12
6
30'
R 11
7
R 10
8
15'
UNITED STATES OF AMERICA
R 9
9
111°00' R 8
0
MONTANA
R 7

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FOREMOST
ALBERTA-SASKATCHEWAN

urface, all weather	dual highway	more than 2 lanes
surface, all weather	2 lanes	less than 2 lanes
or stabilized surface, all weather	2 lanes or more	less than 2 lanes
surface, dry weather		
rack		
ut line or portage		

FOR COMPLETE REFERENCE SEE REVERSE SIDE

Scale 1:250,000 Échelle

Miles 5
0
5
10
Kilometres 5
0
5
10
15
20

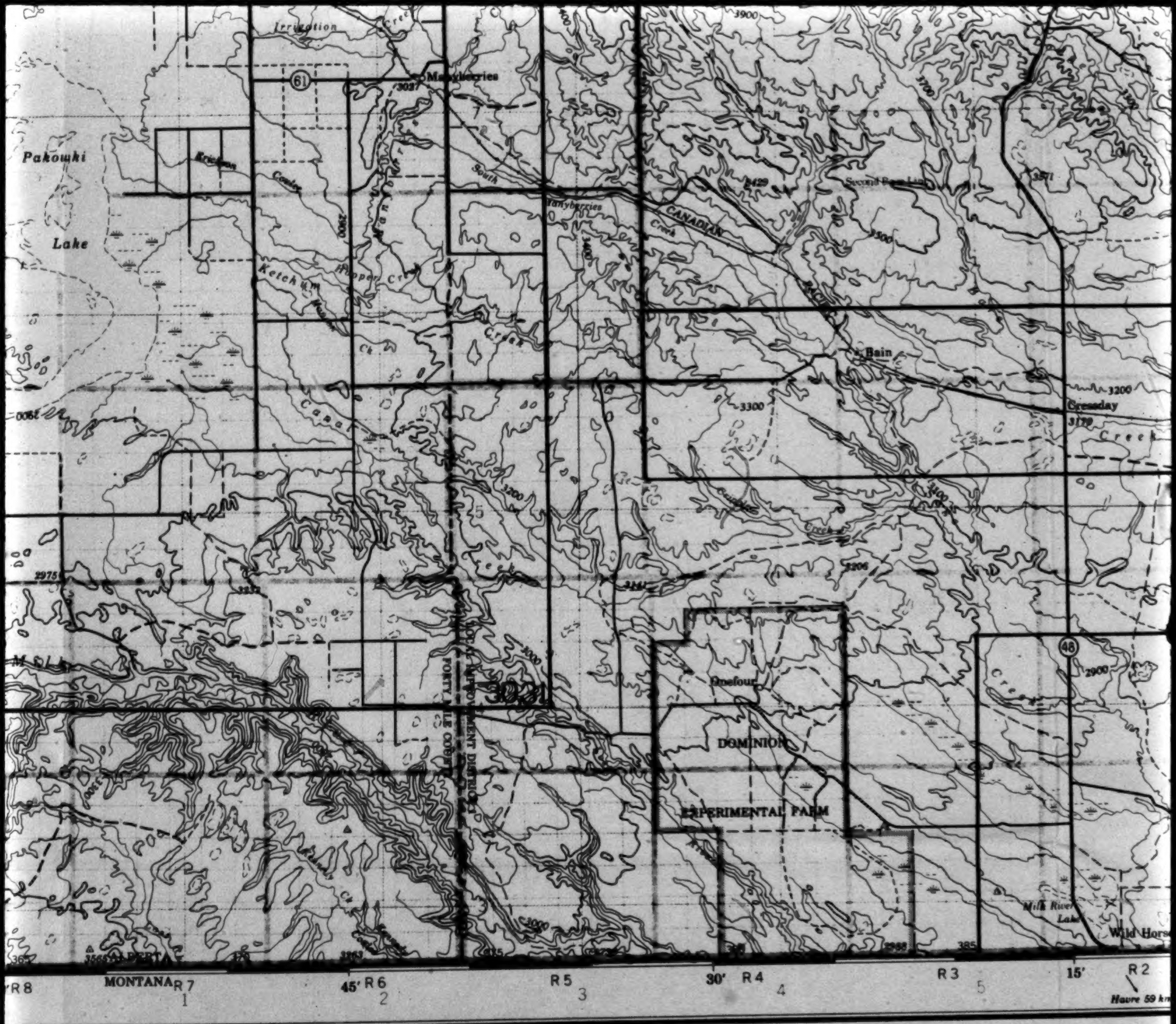
CONTOUR INTERVAL 100 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927
Transverse Mercator Projection

Magnetic declination 1977 varies from 19°16′ easterly at centre of west edge to 18°16′ easterly at centre of east edge. Mean annual change decreasing 5.5′.

ÉQUIDISTANCE DES COURBES 100 PIED
Élévations en pieds au-dessus du niveau moyen
Système de référence géodésique nord-améric
Projection transverse de Mercator

La déclinaison magnétique pour 1977 varie de au centre de la limite Ouest à 18°16′ Est au c limite Est. Variation moyenne annuelle décrois

10 GF


Irrigation
Manyberries
61
3037
Pakowki
Lake
Erickson
Coulee
South
Manyberries
CANADIAN
PACIFIC
Creek
Ketchum
Pipper Cr.
Ck.
Canal
Creek
3900
3700
3600
3500
3429
Second Pump Lake
3571
Bain
3300
3200
Cressday
3179
Creek
3200
3100
3206
3000
2975
3237
3241
Milk
FORTY MILE COUNTY
LOCAL IMPROVEMENT DISTRICT
3231
Onefour
DOMINION
EXPERIMENTAL FARM
48
2900
Milk River Lake
Wild Horse
ALBERTA
MONTANA
3263
3000
2988
385
R 8
R 7
1
45′
R 6
2
R 5
3
30′
R 4
4
R 3
5
15′
R 2
Havre 59 km

MOST
KATCHEWAN

0 Échelle
10 15 20 Milles
15 20 25 30 Kilomètres

ÉQUIDISTANCE DES COURBES 100 PIEDS
Élévations en pieds au-dessus du niveau moyen de la mer
Système de référence géodésique nord-américain, 1927
Projection transverse de Mercator

déclinaison magnétique pour 1977 varie de 19°16′ Est
centre de la limite Ouest à 18°16′ Est au centre de la
rte Est. Variation moyenne annuelle décroissante 5.5′.

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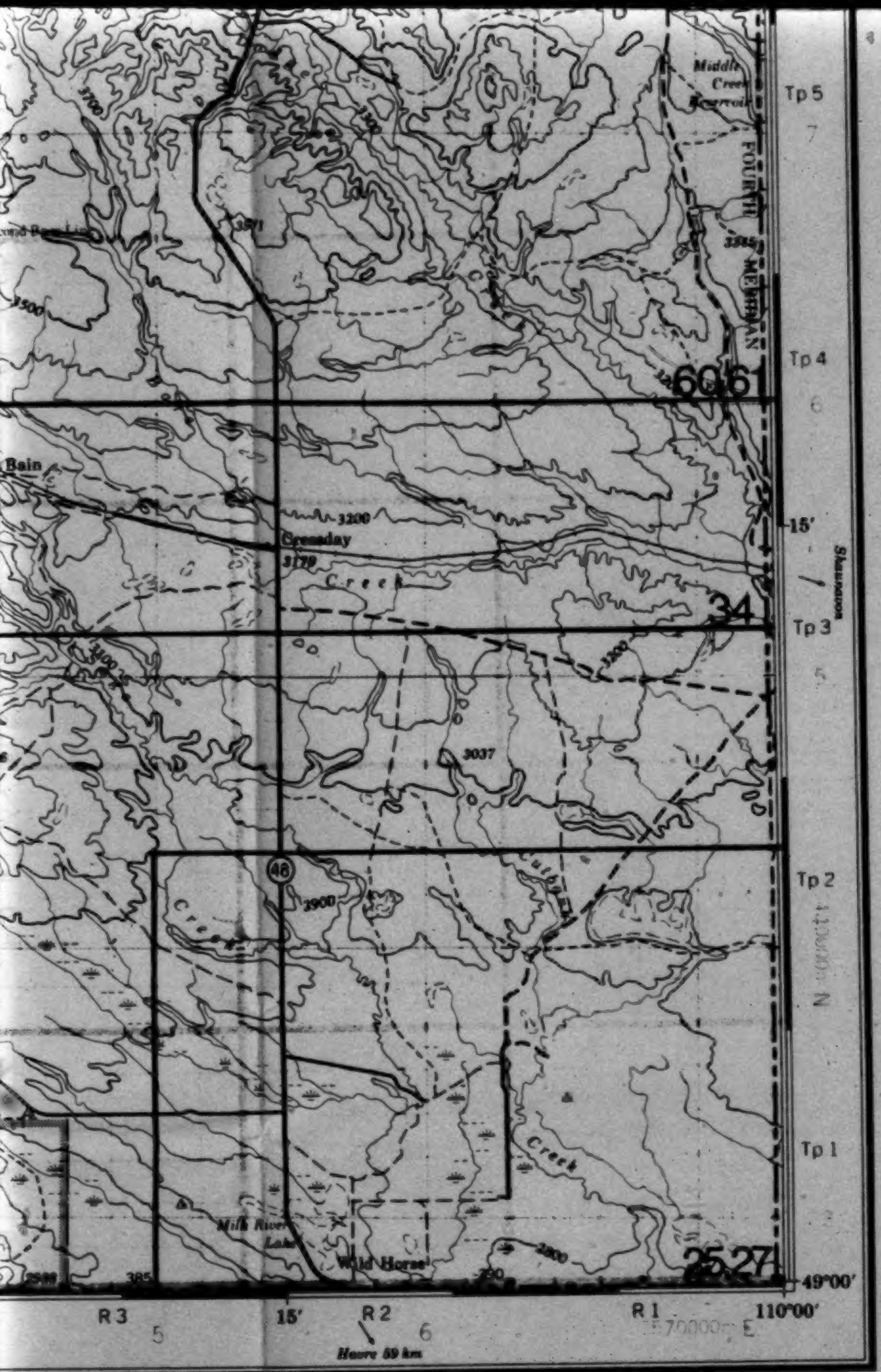
Routes:

pavée, toute saison	2 chaussées séparées	plus de 2 voies
pavée, toute saison	2 voies	moins de 2 voies
gravier aggloméré, toute saison	2 voies ou plus	moins de 2 voies
de gravier période sèche	— — —	
de terre	— — —	
sentier, percée ou portage	- - - -	

POUR UNE LISTE COMPLÈTE DES SIGNES, VOIR AU VERSO

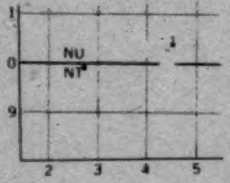
110F


Middle Creek Reservoir
Tp 5
7
FOURTH MERIDIAN
3700
3500
3371
3385
Tp 4
6
60
61
Bain
3200
Crenaday
3170
Creek
15′
Shaunavon
34
Tp 3
5
3100
3200
3037
Tp 2
48
3900
Creek
4100000m N
Creek
Tp 1
Milk River Lake
Wild Horse
2800
2500
385
25
27
49°00′
R 3
5
15′
R 2
6
R 1
110°00′
570000m E
Havre 59 km

OGRAPHIE,
SOURCES.
qu'indiqués

plus de 2 voies
moins de 2 voies
moins de 2 voies

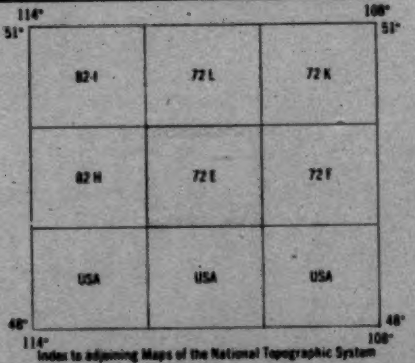
EXAMPLE OF METHOD USED
TO GIVE A REFERENCE TO NEAREST 1000 METERS
EXEMPLE DE LA MÉTHODE EMPLOYÉE
POUR FIXER DES REPÈRES A 1000 MÈTRES PRÈS


1
0
9
NU
NT
1
2
3
4
5

REFERENCE POINT POINT DE REPÈRE	CHURCH-ÉGLISE	(as above) (ci-dessus)
SQUARE Read letters of 100.000m square CARRE Lire les lettres du carre de 100.000m		NU
EASTING Read number on grid line immediately to left of point. LONGITUDE EST Noter le chiffre de la ligne du quadrillage immediatement a gauche du repère		4
Estimate tenths of a square from this line eastward to point Estimer le nombre de dixiemes du carre entre cette ligne et le repere en direction est		5 45
NORTHING Read number on grid line immediately below point LATITUDE NORD Noter le chiffre de la ligne du quadrillage immediatement en-dessous du repere		0
Estimate tenths of a square from this line northward to point Estimer le nombre de dixiemes du carre entre cette ligne et le repere en direction nord		4 04
GRID REFERENCE REFERENCE AU QUADRILLAGE		NU4504

If reporting beyond 18 in any direction, prefix Grid Zone designation as: 14VNU4504

Si vous faites connaître votre position à quelqu'un qui se trouve à plus de 18 peu importe la direction, indiquez également la zone du quadrillage tel que 14VNU4504


114°
108°
51°
51°
82 I
72 L
72 K
82 H
72 E
72 F
USA
USA
USA
48°
48°
114°
108°

Index to adjoining Maps of the National Topographic System

Tableau d'assemblage du Système national de référence cartographique

FOREMOST

72 E

EDITION 3

120F12